Cal Poly India Project

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Statement of Disclaimer

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Abstract

This report documents the research, ideation, and development of a solution, implemented by the Cal Poly India Sanitation Team per the request of Mr. Harish Bhutani, to solve the problem of hazardous human waste management in poor villages in India. The sponsor envisioned a universal design that would give each household in those villages access to a private toilet system because the current solution is open defecation in water sources and farming fields. The initial constraints required the project be low cost, not use of electricity or water, have the ability to cater to an 8-10 person household, and be easily manufacturable and maintainable. Investigating this problem began with research into both the culture of India and the existing solutions. Our initial observations indicated some barriers that would add to the constraints of the design. The research showed that there were many ideas existing that have been either already established or in the early stages of laying the groundwork, but there was an interesting trend with the success rate and contingencies of these past projects. The past projects have not lasted very long due to poorly educating the users, lack of an infrastructure to handle continued maintenance, and lack of efficacy in the users to care for the systems. This last point had a lot to do with cultural taboos of touching human waste and being seen as a low class citizen. With all of this in mind, the brainstorming led to a design that is a hybrid of the past projects. The design implements a concrete-lined pit latrine with a hand pump used every six months to empty the pit and move the waste to an offsite facility. The user will have access to a personal shelter, made of compressed earth blocks, to safely defecate. A key feature includes a water bottle light to magnify the existing light in the shelter. This idea considers the user interaction with the waste, which will be no contact at all. The hope is that this design will also create job opportunities for people when the removal is needed. This would form a tight infrastructure that is integral to the success of this design because the people will be able to make this structure a part of their daily lives without this waste disposal system seeming like a burden. After this design was finalized, construction for the prototype began. The necessary part were ordered and the parts were manufactured to size and assembled. Design considerations that changed during this process included changing the internal metals to steel because of availability and militating on the tooling needed. The prototype was then tested for cyclical performance, as well as strength testing and materials testing. Some final conclusions drawn from the this project are that this a simple manufacturing process and easily maintainable, but in order to have this implemented in a region there needs to be a waste education done as well as continued supervisor and teaching of the users on how to properly care for this system.

Introduction

The goal of the project is to develop a sustainable, safe, and inexpensive sanitation system for underdeveloped communities in India. The problem for these people is that, without a proper solution in place, they have to defecate and dump human waste in open fields outside of their villages. This runoff creates high concentrations of raw sewage seeping into areas where harmful pathogens contaminate agricultural fields and water supplies, causing many people to contract fatal diseases. Some of the main issues are many villages lack education in sanitation and hygiene in connection with health, culture taboos make it unacceptable to be in contact with feces, and past implementation of systems that are not feasible to solving the root of the problem because they are too complex or require too much maintenance to run the systems.

We aspire to come together as a team, and work with Mr. Harish Bhutani, Dr. Mohammad Noori, and a focus village to form a feasible design to meet the needs of our clients. As our specific design will not necessarily be applicable to every village, we will also be developing a guide to determining the best solution for a given locale. In addition, we understand that public education of the importance of personal and community sanitation will play a key role in the success of any design. We hope that our solution can be coupled with an organization which would be able to teach the fundamentals of basic healthy lifestyles to those in need. The implications of the success of this project are great. The design of this sanitation system has the potential to help out a region of people who have not had the means to end this problem of risking contraction of a disease every time a person drinks water. This could also lead to a greater global awareness, better solutions, and applications in other parts of the world with the same problem.

Objectives

Considering the overall objective of creating a sustainable sanitation system, the scope of the project will be defined by the following engineering specifications. Each specification was evaluated using a House of Quality[1] and compared with customer requirements, existing designs, and the other specifications in order to determine relative importance.

The most significant specifications are maintenance costs, construction costs and the enclosed nature of the personal unit. In addition to cultural taboos that discourage handling of human waste, maintenance of the system has been a limiting factor in past attempts to address this issue. Because of this, it is vital to find a way to limit the required involvement with the system once it is implemented. Construction costs as a whole are also a major concern due to limited funding and the massive scale in which this project can ideally be applied. The target cost has been based off of previous design budgets so as to create a reasonable goal although the less expensive the

[1] See Appendix B for detailed view of House of Quality

better. The necessity for the unit to be fully enclosed stems from privacy concerns specifically those revolving around gender roles in India. It will also help considering the environmental conditions which will include monsoons and extreme heat.

The product lifespan, footprint, and distance from user are also relatively weighty aspects of the design. Lifespan goals are based off of previous designs' durability and correspond with current needs in the affected regions. It is possible that the solution resulting from this project will serve as a temporary fix and the lifespan is weighted accordingly. Footprint for the system is limited based on the population density as well as other related specifications such as construction costs. The target distance of the product from the user is related to many other specifications especially user safety considering the gender roles in the affected regions. Ultimately we have decided to aim for individual household units which innately minimize proximity from user.

Certain specifications are simply required even though comparative analysis did not yield high risk in relation to hitting the target values. Water will no doubt be limited or even inaccessible in some applications which lends to the zero gallons per use target; however there may be alternative options so zero water has not been wholly ruled out. The capacity is another specification which cannot be compromised much with as the application requires the product to be used by a relatively high volume of people.

Although universality of the product is a secondary goal, we still hope to incorporate a certain number of interchangeable parts or components so that maintenance is limited and the design can be implemented similarly in a variety of environments. However, we also see the value of targeting specific communities so as to best address the needs on a case-by-case basis.

Sponsor Requirements

Table 1. Objective Specifications for Design

Spec. #	Parameter Description	Target	Tolerance	Risk	Compliance
1	Maintenance costs	3000 rupees/year	± 300 rupees/year	H	A, S
2	Construction costs	17000 rupees	Max	H	A, S, T
3	Fully enclosed	Yes	N/A	H	S, I
4	Footprint	$16ft^2$	± $2ft^2$	M	I
5	Waste capacity	55 gallons	Min	M	A, I
6	Water used	0 gallons/use	+ .25 gallons	M	A, T
7	Lifespan	10 years	± 2 years	H	A, T
8	Capacity	8 people	Min	M	S
9	# Interchangeable parts	5 parts	± 3 parts	L	A, T, I, S
10	Distance to access	5ft	Max	M	A
11	Time to compost	1 year	N/A	L	A, T, I, S

The target values listed above are ideal considering worst-case scenario in all aspects of the specific village. Depending on the circumstances and available resources in a given village, the engineering specification will change. For example, if a village has access to a relatively clean and abundant water source, we will take that into consideration and utilize the available water.

Background

Cultural:

For our cultural assessment, one of the main considerations we need to take into account is the public perception of handling human excrement. For the people of India, this is an area that is reviled and not even mentioned in society. People who have been put in a position to do the job of cleaning out sewage are known as "Scavengers", and they are considered to be untouchables in the Indian caste system. This is troubling because the caste system has been outlawed by the government of India, so there is a lot of existing prejudice for people who have to do this job. The work that Sulabh International[2] has done in recent years to pioneer change has been extraordinary. They have the goal of creating better sanitation systems, spreading awareness about the dangers of untreated human waste, and helping transform the roles of scavengers to that of a role that is not outcast by society. This has also brought in global awareness, with outside organizations coming up with ways to focus on solutions in urban and rural areas. However, these designs have not gained traction in the secluded villages because of overly-complex mechanisms, high cost and maintenance, and lack of support from the villagers to integrate these systems into their way of life. Without proper education and transitional help from these organizations, systems are often not cared for and abandoned. Additionally, extra measures need to be taken to consider gender needs. For women, there is a lack of consideration for their dignity and privacy when using a toilet. This has created unsafe conditions for women, leaving them vulnerable to sexual assault.

Past Designs:

There are many existing concepts and designs that have been implemented regionally and globally. When we undertook this project, we understood that, even though many organizations in the past had tried to create sustainable systems, there was not a solution that had met all the needs of the people who will use the systems. Because the scope of our project is focused on impoverished parts of India, cost will be a tremendous limiting factor in our design. Our predecessors have run into the problem of designing or installing systems that require a large capital cost and high upkeep charges. In our research we also found that the previous projects only focused on one aspect of the entire problem, namely the toilet/septic structure. There is a lack of consideration for the entire process of having a clean, sustainable cycle while solving the issues of providing a safe and private household toilet system, prevention of harmful pathogens and byproduct seeping into the water supply, treatment of the waste, disposal of the treated sewage that allows for cultural sensitivity and safety, and a simple system with easy maintenance so that the villagers may be able to own this system, increasing the efficacy of each person who

[2] More information can be found at http://www.sulabhinternational.org/

uses this toilet. The following projects have had their own merits, and we plan to take utilize all of our resources to come up with something that can build upon the work of these past systems.

Two-Pit System - Sulabh International[3]

Sulabh International has provided an alternative to open defecation. Sulabh International has successfully implemented a two-pit public toilet system in thousands of locations. This design is hygienically and technically appropriate for Indian communities. It has proven to be acceptable by Indian societal standards and cultural traditions. The two-pit system allows one filled pit to decompose, removing the foul smell and greatly reducing the amount of pathogens in the waste, making it safe for handling, while the other is in use. The pits are lined in brick, stone, burnt clay, or cement concrete rings to provide structural support. They are placed one meter apart from each other, and 3 meters from open wells and shallow hand pumps providing ground water to prevent contamination. Problems with this design are the use of 1.5 to 2 liters of water for flushing, daily maintenance is required, they are communal, and there is no bottom lining (so nitrates and other harmful concentrations of gases can create harmful contamination).

Ecoloove[4]

Ecoloove is a Port-a-Potty like system that has an ongoing business advantage. A bamboo toilet room, with a simple urine diversion squatting pan, is mounted on a three-wheel bicycle. Users climb in, relieve themselves, and the feces are collected in a bucket underneath. The urine is diverted via a pipeline into a black container designed to dehydrate the fluid. Sawdust is used to dilute the feces. The company providing the toilets takes away the full unit, replaces it with a fresh one, and sells the compost. Benefits include employment opportunities, no need for water, and the producing 100% biologic fertilizer. Problems include the toilet's temporary nature, high maintenance, and it serves as a community restroom.

[3] Find more information about the Two-Pit System at http://www.sulabhinternational.org/content/two-pit-system. See Appendix A for visual of Two-Pit System

[4] Find more information about Ecoloove at http://www.ecoloove.com/.

Figure 1. The Ecoloove portable sanitation system

Full Cycle Engineering[5]

This is last year's design from the group that focused on accommodating a community of 100 people. This design went the route of dry composting the human waste by using 32-pit system to breakdown the harmful pathogens. It would work cyclically over a 16 month process per pit. Each one would be filled with any type of waste until it is full (4 months) and then be sealed until fully composted (12 months). Because this was a community driven project, it is not applicable to the scope of our current project. Also, the size and cost were too vast to be installed in a village of 100 people. However, a benefit was the utilization of dry composting by using a diverting valve to send urine a separate tank. The construction of the tanks was structurally sound and the inclusion of a ventilation fan made of bicycle parts was innovative.

The Gulper

A concept that we drew heavily from was the Gulper pump implemented by Wateraid. Designed by British engineer Steven Sugden, the Gulper has been used in areas of Africa and East Asia with pit latrines. The device simply pulls human waste up through a pipe. The pump is permanently attached to both a vertical pipe and cemented to the ground. Water is required to create slurry which can be drawn up to the surface which then is diverted into plastic 200 liter barrels. These barrels are taken to an off-site facility to be disposed. The design utilizes two butterfly valves which alternate opening and closing to allow for sludge to be drawn up and out

[5] Information on the Full Cycle Engineering design taken from senior project report. Pranger, Meghan, Tommy Lauderdale, Joe Benyon, and Kyle Moore. *Design of a Sustainable Toilet*. Rep. N.p. 4 Dec. 2013. Print.

of the pipe. The pump handle is similar to that of a bicycle pump and can effectively begin retrieving waste within three to four pumps. The bottom valve also has a cage attached which blocks large or unwanted debris from clogging the system. Currently priced around $160, Wateraid aims to create safe and efficient waste handling and removal at a reasonable price. In addition, the Gulper helps to create jobs by employing locals as waste management personnel. Based on a model of cleaning two latrines per day, Wateraid estimates that a crew of four can pay back their investment in ten working days. This accounts for the renting of a truck, the fuel for transporting the waste and the wages of the workers. The main challenges that Wateraid has faced include the durability of the units, the human resource reliability and other logistical issues.

Patents

There are already several patented devices that are related to the project. These patents will shed light on what has or has not been successful. Furthermore, they will make sure that no current design is outright copied.

The first is a U.S. patent for a waterless toilet system[6]. The design is portable, waterless, odorless, and “cost-efficient.” This design will be a good reference since it is portable and waterless. Being described as cost-efficient is nice, but that is a subjective descriptor. Odorless is another desirable feature but this does not seem to be accurate considering the process of this design.

A sitting unit is attached to a base section that encloses bags for receiving waste. The bags have chemicals and enzymes that reduce the pathogen level of the waste. A sealing mechanism closes the bags when full and a secondary release mechanism drops the bag. Below the unit is a holding tank where the bags are dropped which is lined with a biodegradable garbage bag.

It is important to note that you still need to do something with the waste when the storage bin is full. At this point it is safe to handle because there will be no direct contact since it’s in the bags. Two possibilities are to turn it into biogas using gasification or fertilizer through composting. Composting would be the simpler of the two.

This design can be retrofitted for existing portable toilets or used as a stand-alone unit for the transportation industry, or in the case of this project, poor, rural areas. Also, most of the unit is constructed from plastic which is a cheap, available material.

The second patent is for a system with multiple filtering stages[7]. The stages are separated to help deal with two types of water that need to be treated, grey water and black water. Grey water does

[6] US Patent #20130212796; Morries, Elizabeth. Waterless Toilet System and Methods of Use. Sanitation Creations, Llc, assignee. Patent US20130212796 A1. 20 Feb. 2013. Print.
[7] European Patent #0495019 B1; Humphrey, Frank. Sanitation System. Patent EP0495019 B1. 11 Apr. 1991. Print. See Appendix Figures 2 and 3 for diagram and test results.

not have a great pathogenic load and comes from the shower, dishwasher, etc. while black water carries a significant pathogenic load and comes from toilets. Black water is treated in an initial black water treatment digester. This treated black water is then mixed with the grey water in a combined digester that further removes solids from the water. This is then discharged to a final combined digester. This then passes through an activated carbon filter before reaching a holding tank. This design opts to use aerobic digestion for all stages. Aerobic bacteria consume oxygen when they break down food which in this case is the suspended solid. Aerobic bacteria are much more efficient at eating up waste than standard anaerobic bacteria.

This design assumes a household with two low flush volume toilets and normal appliances such as garbage disposal, washing machine, and dishwasher. The black water treatment digesters have capacities of about 10 gallons while the combined digesters have a capacity of about 75 gallons. The holding tank has a capacity of 100 gallons. Tests were run at various times to see the amount of suspended solids in each stage of the system. The amount of suspended solid reduction is quite significant. From the data, the amount of suspended solids in the combined digester can be anywhere from a few hundred to over 10,000 mg/l but by the time it passes the carbon filter into the holding tank, the amount is only around 60 mg/l.

Health and Safety Considerations

With organizations like the World Health Organization (WHO), UNICEF, Sulabh International, and NSF[8] working around the clock to address various health problems. They have created many standards and initiatives to ensure that people who work on projects, with the goal of helping regions in need, follow protocol and solve solutions in an appropriate manner. From our research, we found applicable guidelines to keep in mind for our design process.

The surface soil should not be contaminated.
There should be no contamination of groundwater that may enter springs or wells.
There should be no contamination of surface water.
Excreta should not be accessible to flies or animals.
There should be no handling of fresh excreta; or it should be kept to a strict minimum.
There should be freedom from odors or unsightly conditions.
Granular fertilizer product is free of pathogens, is noncombustible and meets pathogen reduction requirements.

[8] See the webpages of these organizations: http://www.who.int/, http://www.unicef.org/, http://www.sulabhinternational.org/, http://www.nsf.org/

Design Development

Previously in our project, we have been established as a team to work on the implementation of a sanitation infrastructure in villages in India. We then met with Dr. Noori and Mr. Bhutani to formally introduce ourselves and discuss expectations for this year-long project. After that, we began to conduct background research; we used past senior projects, Sulabh International's development, journals on health concerns, cultural assessments, meetings with Engineers Without Borders, and patent searches. Finally, we came up with a Quality Function Deployment (QFD) tool to determine the weight of each need and the relationship between certain technical specifications. We then compiled our work to draft a project proposal to our sponsor to state the direction and intentions of our group for the next year.

The next step was to brainstorm ideas to build a concept that will become a feasible solution to this problem. In this stage, we developed a list of critical functions for the design. Ideation was conducted using brainstorming, "brainwriting" and SCAMPER methods to compile a multitude of ideas for each function. Then we threw out unrealistic or unfeasible ideas and further evaluated our top concepts with Pugh matrices. This compared each concept with a datum, in most cases Sulabh International's Two-Pit System, to see how they stacked up in relation to each customer requirement. This evaluation fails to consider the importance of each requirement in relation to each other so the next step was to compare the concepts with weighted decision matrices. The decision matrices yielded much more useful results and helped us to select the best ideas for each function.

Concept Generation

The relevant functions for a sanitation system were accessing fluid, eliminating odor, eliminating/sanitizing waste, providing visibility, separating waste from user, sheltering user, storing waste, and transporting waste. Accessing fluid is generally meant for water if it's available in the area but could also be for urine or wastewater that can be recycled back into the system.

Concept Selection

Eliminate Waste[9]

The most important function of the system is the sanitation of the waste to the extent that there is little to no danger of contaminating drinking water. Three solutions were thrown out immediately from the Pugh Matrix. These included compacting waste, throwing waste into water, or throwing waste into ditch. The last two are a couple of ways waste is currently handled in many parts of

[9] See Appendix B for the Pugh matrix and weighted decision matrix respectively for "Eliminate Waste"

India. These clearly are not safe for locals' health but they usually do not realize this or don't have the means to implement any other solution.

The Decision Matrix left only two solutions, which were bacteria (anaerobic and/or aerobic) and composting. Burning was discarded because the smoke and fumes would be a health hazard. Also, this would require more work for the women in a village because more fuel would need to be gathered. Converting into fuel was discarded because the process often requires time and effort to work. This would probably not be viable as it is looked down upon to handle waste. Even if converting the waste into fuel were managed correctly, it is questionable if villagers would be willing to use it as fuel. The last discarded solution was a solar reflector. It was actually a great solution, but the costs and operation of a solar reflector were too much.

Shelter User[10]

A structure will be required to shelter the user. The three most important points to keep in mind are that the shelter needs to be as safe as possible for women, be able to handle harsh weather conditions, and be made from cheap/accessible materials. For these reasons, a tent shelter, basement structure, and others were eliminated from the Pugh Matrix.

The Decision Matrix left three solutions which were outhouse, compressed earth blocks, and trees. Combining trees with the tent solution would be extremely cheap and work fairly well for rainy weather. This would have been a large tarp hung across trees in an area with shrubs and plants that provide privacy. This idea was thrown out because it cannot be expected that such an area will be available in a given location. The best solution is the already common outhouse but this time made with compressed earth blocks. Compressed earth blocks are cheap, easy to create, easy to build with, and water resistant. It is important to note, however, that the compressed earth blocks cannot easily be used for any below ground part of a structure. Also, while they are water resistant, they are not waterproof so they cannot be used in conditions where they may become partially or entirely submerged by water.

Access Fluid[11]

Analysis for the function of accessing fluid is meant only for situations where water is available with relatively simple accessibility. The Pugh matrix datum for accessing fluid is based off of Sulabh International's method which consists of users transporting well water via buckets in order to flush waste. The results of the Pugh matrix do not show a clearly superior method but the two best appear to be either some type of hand pump or the use of an alternative fluid (perhaps liquid human waste). While diverting water through a pipeline from the mountains or collecting rainwater has many advantages, they are simply not possible in many locations and may only be functional for certain parts of the year. Using an alternative fluid has a one "+" advantage but presents a possible health hazard which plays a role later when using a weighted

[10] See Appendix B for the Pugh matrix and weighted decision matrix respectively for "Shelter User"

[11] See Appendix B for the Pugh matrix and weighted decision matrix respectively for "Access Fluid"

decision matrix.

Under further analysis, using a weighted decision matrix, there is a clear frontrunner. Using an alternative fluid has dropped to second to last due mainly to safety concerns. The datum has proven to be a fairly solid solution but is outscored by the hand pump. A hand pump is useful as it can be used in individual households, is relatively safe and does not require extensive maintenance. The use of human power is preferred as it encourages personal ownership and does not require electricity.

Provide Visibility[12]

The goal for analyzing the visibility in our enclosure is mainly for the safety of women who will be using this system at poorly-lit times. Because our design will include an enclosure with a roof, we will need a way for people to see when they use our system.

The Pugh matrix for providing visibility posed the datum, Sulabh Internationals solution, which is to just have an open roof. This is good because it saves on materials and it can let in a lot of light. However, it cannot adjust to the environment, and the lighting is limited to daytime (posing a threat to the safety of women). The successful ideas that came out of the matrix were the water bottle light, the lantern, and the glowing objects. We initially liked the water bottle light because it is a good, inexpensive way to use refraction to spread out the natural light in a room while not having a hole in the roof to expose the user to the elements. This design falls short in providing light during night, though. The glowing objects is simple, but the longevity of these sources of light aren't good, they are not local, and the amount of lumens being put out would not be enough to provide adequate light. Human and solar-powered lighting would not work because of high maintenance costs and high capital pricing. The reflective strips (a combination between solar panels and glowing objects would be cost effective, provide safe lighting at all hours, and be low in maintenance. The decision Matrix will show more clearly the weighting for each evaluation we make for these ideas.

The decision matrix for, providing light in our enclosure, made the ideas more clear-cut as to what would benefit the user the most. The Sulabh International method and the water bottle solution were the front runners for options. The human and solar-powered lights were in the same position as before. The real change came in the solar reflector lights. Because the weighting of the criteria placed more emphasis on the safety and low cost, rather than universality and being used in individual households, it became the top pick for implementing and appropriate light source for a village in India.

[12] See Appendix B for the Pugh matrix and weighted decision matrix respectively for “Provide Visibility”

Store Waste[13]

For the Pugh matrix, the datum used for comparison is Sulabh International's Two-Pit System in which the waste is stored in one of two pits and then later diverted into the second to allow the first to decompose. A septic tank is similar in many ways to the Two-Pit System but would most likely be more expensive and perhaps be more safe under a more diverse set of environmental conditions including those without water. Lagoon systems and settling tanks look to be more beneficial in that they would require much less maintenance and could more likely be designed using local materials. These two models could also work with no water but are susceptible to higher construction costs in that they are larger systems than the datum. The plastic container, while appearing to be the ideal concept, may have some present some issues that are harder to overcome. Although it would be applicable for individual households, cost nearly nothing, and work in any environment or setting, the main drawback is that this design requires extremely frequent "maintenance" in that the user would have to dispose of waste every other day or perhaps even daily. Considering Indian cultural taboos regarding the act of dealing with human waste, this option is not viable. As a result, the top concept seems to be either a lagoon system or a settling tank of some kind to be used to store the waste.

The decision matrix for waste storage further confirmed the strengths of a lagoon system and settling tank as both scored the same (70). Two big factors that contributed to high scores for each of the aforementioned ideas were the low cost requirement and the necessity for safety to the user. The datum scored significantly lower in the safety category as a high groundwater table could be severely contaminated if sewage leaks through the pits. As the plastic container requires a high rate of maintenance, it increases the chances for the user to come in contact with feces that may contain disease. The most significant specification was evaluated to be low maintenance which hurt the datum as well as septic tanks and plastics containers. In lieu of the results of both the Pugh matrix and decision matrix, we are still deciding between a lagoon system and a settling tank.

Transport Waste[14]

We then looked to see at a solution to address the need of moving the waste from a storage pit to a place where it can be safely disposed. The Pugh matrix for this function included six ideas compared to the Sulabh International solution, which would be to fill up both pits and manually move the waste out of the pits after they are finished after composting (1 year). This may be a problem because of cultural taboos in touching human excrement mixed with lack of education in composting. The ideas proposed were a human-powered vacuum pump, corkscrew plumbing to an offsite facility, a push stick to move the waste through a plumbing line into a storage tank, composting bin on wheels, above-ground plumbing to a tank, and collection bags. The matrix shows that the pump, collection bag, and push stick would be good because they are cheap

[13] See Appendix B for the Pugh matrix and weighted decision matrix respectively for "Store Waste"
[14] See Appendix B for the Pugh matrix and weighted decision matrix respectively for "Transport Waste"

solutions. The vacuum pump can be built with local materials and maintenance can be minimal. The push stick idea is impractical, but because of the lack of weighting it was able to be included with the "good" designs. The corkscrew idea was innovative however the idea is impractical with the space we are restricted to, the use of imported materials, and the high maintenance that would be associated with implementing the design. The collection bins could require too much upfront cost and maintenance to make the collection bins work. The above-ground plumbing would be expensive, require advanced machines, and be unsafe for the surrounding houses. Ultimately, the decision matrix will tell whether or not the ideas will hold true in their standings.

The decision matrix showed very similar results with the initial analysis. The only change was that the corkscrew plumbing became an important idea to consider, but we still believe that it will be impractical to consider. The vacuum pump is the best decision for moving the waste away from the area where the waste is initially stored.

Final Design

Overall Description

The final design consists of a shelter, cylindrical pit and pump system. It is important to note that the shelter and pit are distinct to each unit but that the pump is to be used for a large number of units. In other words, the pump has been designed to be detachable for the purposes of hazard prevention and cost reduction.

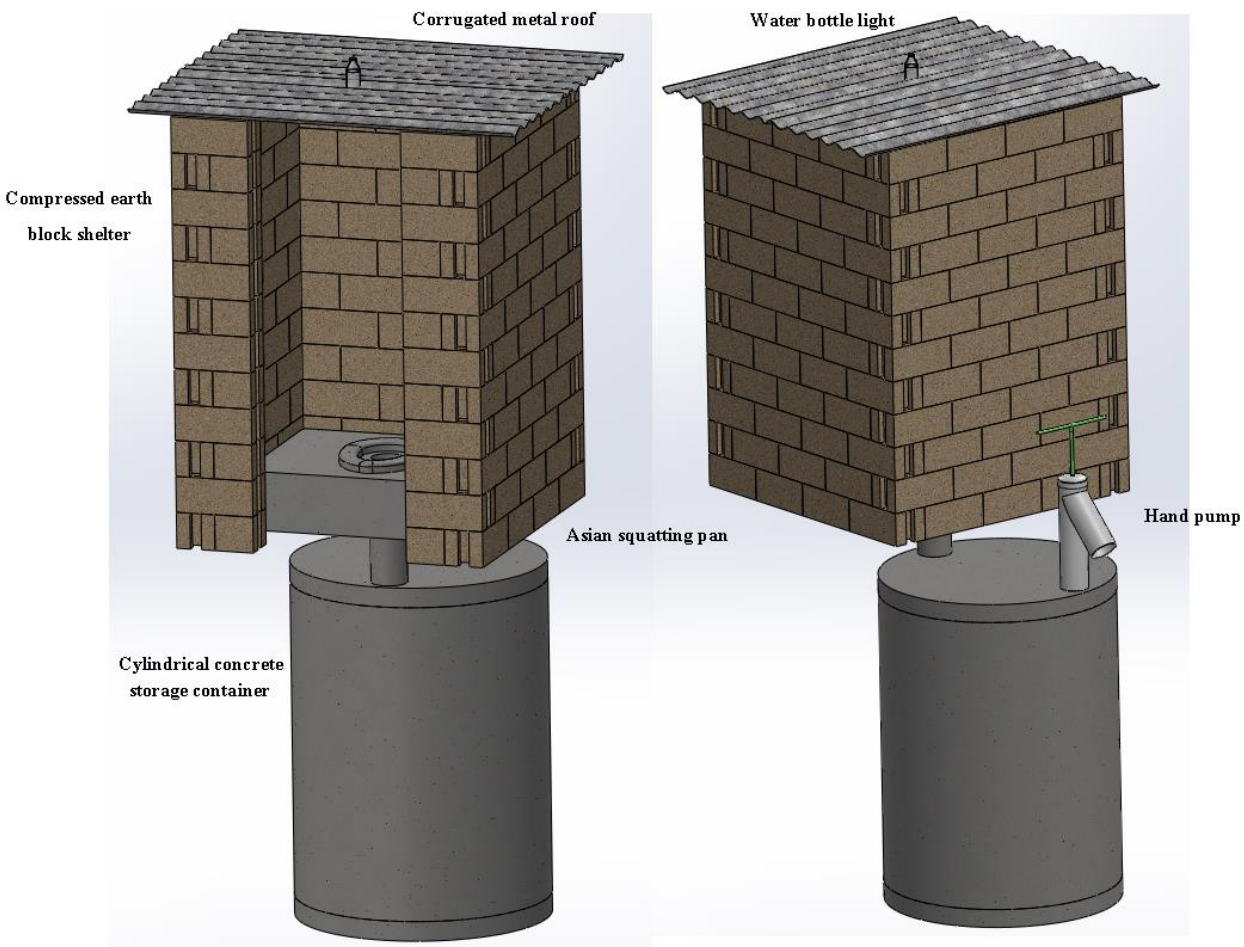

Figure 2. Front and back views of final design

Detailed Description

The shelter is single occupancy and is to be constructed primarily of compressed earth block walls with a corrugated sheet metal roof. Ideally the blocks with be formed using a block press[15]. This type of block press can be used to make building materials for virtually any sized structure and can provide employment opportunity for individuals looking to expand or improve the village through sanitation projects as well as any project which involves constructing buildings. The blocks consist of a mixture of sand, clay and concrete and can almost certainly utilize local soil for a portion of the block mixture. The corrugated roof sits atop the blocks overhanging by six inches on each side. The overhang is essential for diverting rainwater from the blocks. The integrity of a compressed earth block suffers when saturated with water so the excess roofing accounts for adverse weather conditions.

To provide lighting during the day, a plastic bottle containing water with bleach will be inserted into the corrugated sheet metal. Light from the sun will refract through the water in the bottle and illuminate the room with light equivalent to around that of a 55 watt light bulb. The water will contain bleach to prevent mold and bacteria from growing in the bottle which would obscure the incoming light. The bottle should be one to two liters, filled to the cap, and contain 1 part bleach for 200 parts water. To prevent rainwater from leaking through the hole for the plastic bottle, a rubber sealant will be applied between the bottle and hole.

Inside the shelter there will be a simple squatting pan. This is a simple and cost-effective solution for a medium through which the waste can pass into the concrete pit below. The pit will hold upwards of one cubic meter of waste which we have determined as more than enough for the six-month time span we have determined as necessary between waste removals. The cylindrical design is one which has been implemented in Cambodia where villagers have essentially cast the concrete cylinders in the ground and used a crude pulley system to hoist the pits out of the ground for transport to the site of the latrine construction. In addition, we have decided to enclose the pit on both the top and bottom. Enclosing the top will be necessary for limiting undesirable smells as well as preventing people from accessing the waste. Compressed earth blocks will form the main walls for the shelter, approximately four feet by four feet and standing six and a half feet tall. The walls provide a safe and relatively comfortable area for the user while protecting against natural elements acting as a physical barrier between the users and their waste. Sealing the bottom of the pit is extremely important in that it will impede nitrates from leaching into the ground and potentially leaving a negative impact on the groundwater table. As many villages use groundwater for drinking, it is critical that the groundwater remains unaltered. Leading up from the pit will be a long segment of four inch PVC piping which will be the path by which waste is pumped out. This pipe will protrude roughly one foot above the ground's

[15] See Appendix A for a picture of a compressed earth block press

surface and will be capped off to again provide a means by which to separate the user from the waste below.

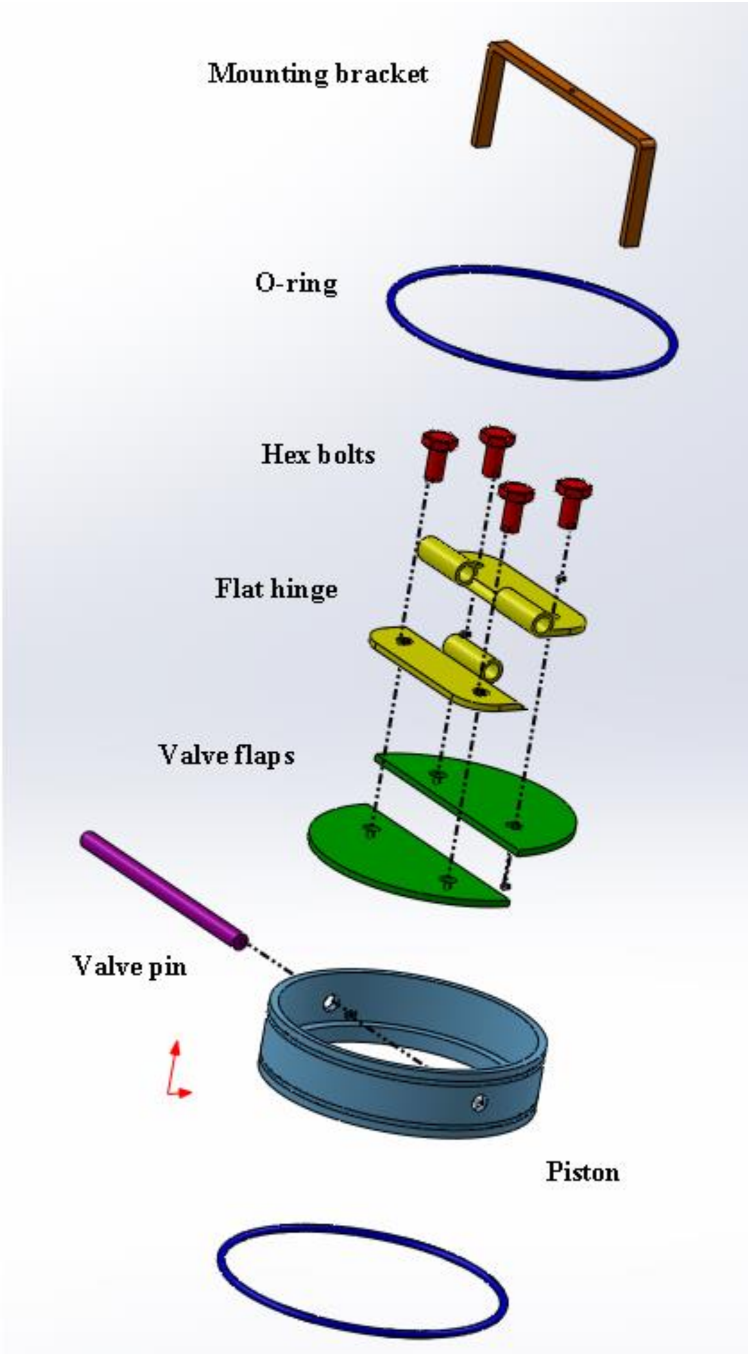

Figure 3. Exploded view of pump piston assembly

We have placed particular importance on the pump as it is the truly unique aspect of this project that addresses the most design requirements. As mentioned previously, the pump is separate from the rest of the unit in that it is meant to be handled exclusively by trained individuals wearing proper personal protective equipment. The pump consists of a plunger[16] with a piston attached to the bottom which is run through a segment of PVC piping which directs the slurry into plastic containers via a spout above ground. The piston has a counterbored chamber with a butterfly valve inside. This valve, in conjunction with a check valve located at the bottom of the pipe coming from the pit, draw waste up and out of the pit. The check valve at the bottom of the pit is pinned to the walls of the pipe and held steady by a female PVC adapter. Initially the plunger is drawn up, allowing sludge to flow past the stationary check valve. When the plunger is pushed back down, sludge flows through the butterfly valve attached to the piston while the downward force closes the flaps on the check valve. When the plunger is drawn up again, the butterfly valve closes and the waste is lifted up the pipe. After three to four strokes the slurry will have reached the top where a 45 degree angled spout allows the mixture to drop down and out of the pump chamber. The waste is directed into large (roughly 200 liter) plastic containers which can be transported to a waste facility for disposal. The function of collecting and disposing of the waste can be developed into job opportunities. As the pump is reasonably priced, an individual or group can purchase a pump and service their community easily making up the initial cost in a relatively short time period.

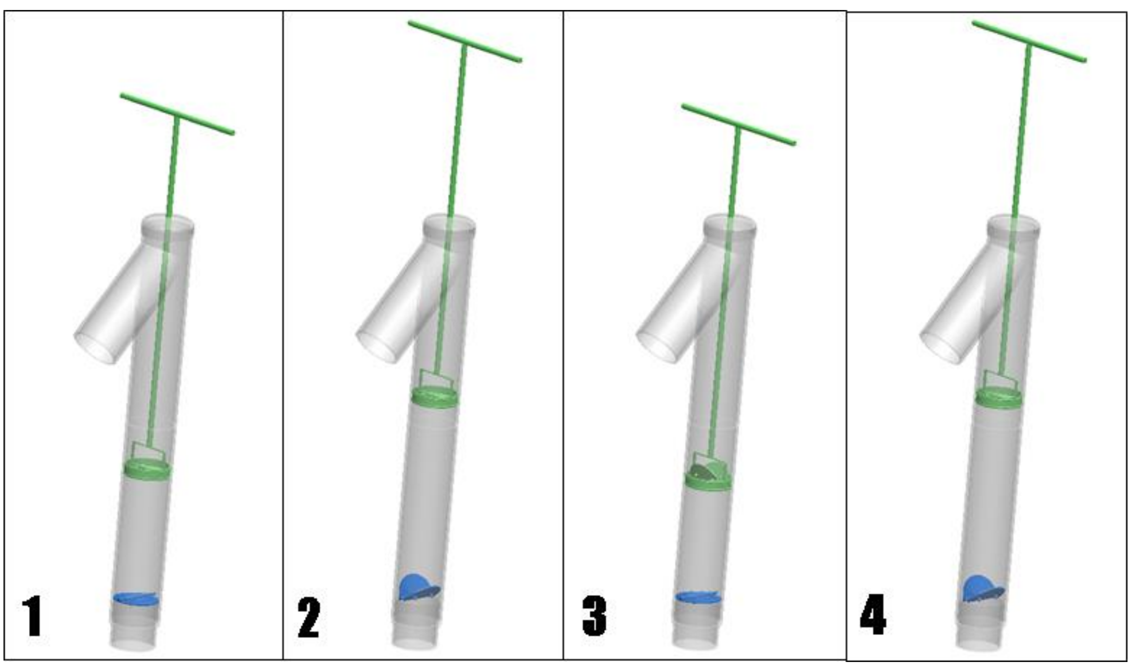

Figure 4. Step-by-step simulation of pumping process- 1) Piston is pushed down into suction pipe 2) Plunger is pulled upward drawing slurry into middle chamber 3) Piston pushed back under the slurry 4) Plunger pulled back upward drawing slurry out as more is brought into the middle chamber

[16] An exploded view of the plunger assembly can be found in Appendix C

Analysis Results

Pump Suction[17]

When comparing our ideas with the design of the Gulper, we sought out three ways to improve the concept of the pump. We looked to make it cheaper, make it easier to be manufactured by people in villages (or people serving poor villages), and design it to service 100 families. Our end goal was to create a pump that could be handed off to anybody and be used to change the social infrastructure of the areas using this product.

Before we sought out to implement these big changes, we had to check the validity of the system to make sure that the pump would work in within our specifications and in extreme conditions. Specifically, will it be able to move the waste without the use of water to help the degradation process? In order to find this out, calculations for the total density of the slurry after 6 months, the viscosity of the slurry, the frictional force applied at the PVC walls, the suction force, and the head of the slurry. These were done with worst case scenarios in order to find the maximum performance values of the pump. Assuming average rates for human waste (feces and urine) being produced in 6 month period and very little degradation over that time period, we found that the density of the slurry in the latrine to be 1.14 kg/m^3 and a dynamic viscosity of 70 $N\text{-}s/m^2$. With these values and not accounting for losses, a weight of 26 pounds of force is needed per stroke to draw up the slurry of the liquid. Now, with the assumptions that this slurry will behave like a Newtonian fluid when traveling through the pipe, it takes about 4 strokes to raise the fluid to the top, that the strokes from the user will be happening at a constant rate, and that flow through the valves will have negligible effects. Taking these into consideration, we find that the volumetric flow rate is $2.4x13^{-3}$ $m^{\wedge 3}/s$ and the velocity to be $3.0x10^{-1}$ m/s. Then a friction factor of 90.96 was found. Using an online calculator, head losses were found to be 4.7 m., with a pressure drop of 76.1 kPa.

Taking all of these calculations into account, the pump will be functional and will not be strenuous on the user to lift up the slurry. Having all of these calculations in mind, we then looked at the tolerances of the fitting between the pipe and the piston. We found, through research of the Gulper, that these tolerances do not have much effect on the suction factor of the pump if the measurements are fairly small in discrepancies.

Plunger Bracket[18]

The bracket that attaches the shaft to the piston is being made from aluminum. The maximum stress on the bracket was calculated to make sure the yield strength of aluminum was not exceeded. By modeling the upper portion of the bracket as a simple beam, the maximum moment

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[17] For pump suction calculations, see Appendix D

[18] For plunger bracket calculations, see Appendix D

was found to be 30lbf in, or 2.5lbf ft. This was assuming that there was a 30lbf lifting force in the center of the beam and two 15lbf reactions at the ends of the beam. Initially with a ¼” width and 1/10” height, the maximum stress was too great. The height was adjusted to ¼” and the resulting stress was 11,520psi. With the yield strength of aluminum being 40,000psi, we get a factor of safety of 3.5.

Pit Calculations[19]

While it is not expected that the concrete pit would fail, basic stress calculations were done to check. The pit is only under about half a foot of earth so the normal stress on the pit walls at the bottom is less than 8psi. The resulting factor of safety is 420 so there is almost no chance of failure from normal stress. Hoop stress from a full tank is 1340psi which is of some concern but the factor of safety is still 2.25.

Cost Analysis

We did a cost analysis for the entire system, separating it into two bills of materials. The first is for the removable pump which will service multiple units, while the second was for the housing structure, pit, and suction pipe that each individual unit will have. The pump accounts for a third of the entire system costs which is why it was made removable. The costs associated with the pump will be distributed among however many units it services so the end cost per unit drops considerably. The pump prototype costs come to $63.17, while the cost for everything else is $125.65. Further research will be done to bring prototype prices down if possible. The manufacturing costs will certainly be less than the prototype costs by buying in bulk. From using quotes for large purchase orders of PVC pipe and couplings the manufacturing costs has already gone from $125.65 to $91.21. This is expected to drop further once quotes for large purchase orders of cement, sand, and gravel can be attained.

[19] For plunger bracket calculations, see Appendix D

Table 2. Pump System Bill of Materials

Component	Prototype	
	Quantity	Price
Band Clamp 4"	1	$11.99
4" PVC Wye (45° Tee)	1	$5.99
4 in. Schedule 40 PVC Cap	1	$5.34
Aluminum Round 0.5" 2011-T3 (4 ft.)	1	$8.70
4-1/2" Aluminum Round 6061-T6	1	$8.76
Aluminum Bare Sheet 1100 H14	1	$13.61
Stainless Steel Utility Hinge	1	$6.99
1/4-20 x 1/2" Hex Bolt	4	$0.20
1/4" Steel Round Bar	1	$0.86
Buna N 4" O-Ring	2	$0.73
Total		**$63.17**

Table 3. Bill of Materials for Single Prototype and Large Manufacturing Run

Component	Prototype		Manufacturing	
	Quantity	Price	Quantity	Unit Price
Internal Coupling Sch 40 4"	1	$5.36	100	$4.39
Aluminum Bare Sheet 1100 H14	1	$13.61	1	$13.61
Stainless Steel Utility Hinge	1	$6.99	1	$6.99
4" PVC Schedule 40 Pipe (4 ft.)	1	$15.36	100	$13.83
Undergound Pit Cement 94#Portland	1	$9.98	100	$9.98
Gravel	2	$19.96	200	$9.98
Sand	3	$29.94	300	$9.98
Corrugated Sheet Metal Roofing (5' X 5')	1	$13.25	100	$13.25
Water Bottle w/ Chlorine Water	1	$1.20	100	$1.20
Eastern Toilet Pan	1	$10.00	100	$8
Total		**$125.65**		**$91.21**

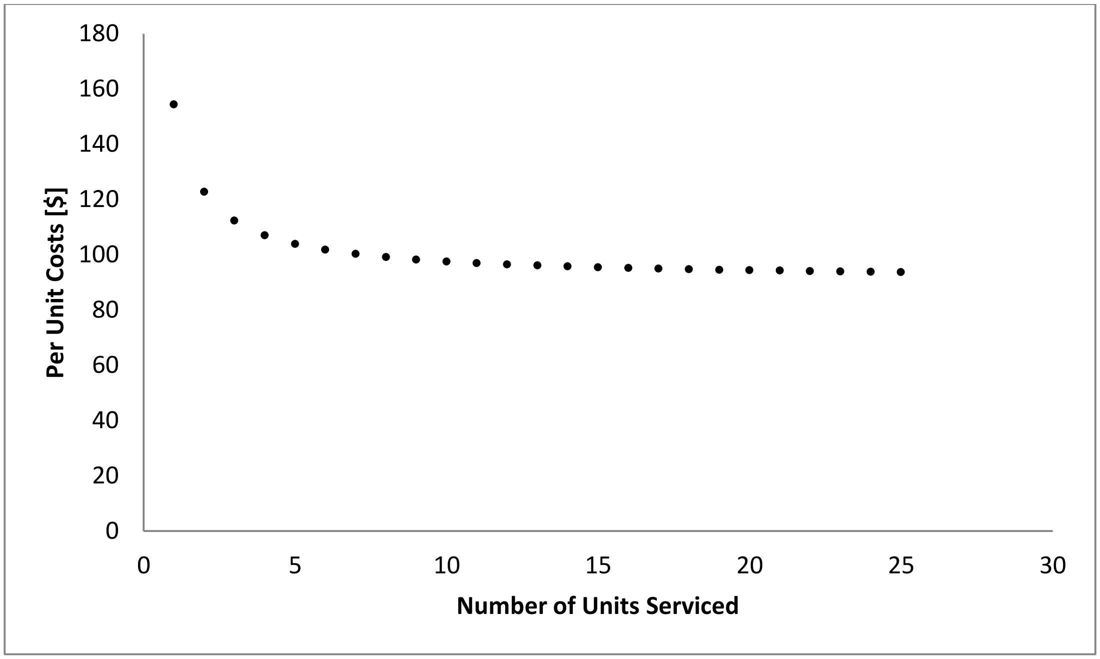


Figure 5. As the number of units serviced by a single pump increases, unit costs drop

The price per unit as a function of units serviced by a single pump can be seen in the plot above. Once one dozen units are being serviced by one pump, the savings approach 40% as compared to one pump for every one unit.

Material, Geometry and Component Selection

To keep the design simple, the least amount of materials were chosen. For the pump, the two main materials selected were aluminum and PVC pipe. Aluminum was chosen because it is lightweight, abundant, cheap, and can be shaped. It also does not rust due to a thin protective layer of aluminum oxide forms on the metal's surface. PVC pipe was chosen because it is cheap, lightweight, and easy to work with. Overall, all materials selected will not corrode or deteriorate in the presence of water.

The pipe handle is going to be T-shaped with a 0.5" diameter and made from aluminum. The handle will be 14" wide and the shaft will be 34" long. The handle width allows for comfortable use by the user. The bracket that attaches the shaft to the piston will be formed from aluminum sheet. A ¼" diameter hex bolt will secure the bracket with the piston. The 4½" aluminum round will be for the piston and machined down to an outer diameter of 4.02". The inner diameter will be 3.77" but a lip will be kept at the bottom with a diameter of 3.42". The piston will be 1" high while its lip will be ¼" high. There will be two a ¼" diameter holes through the piston so that the pin of a flat hinge can be press fit in. The aluminum sheet will again be used for the flaps of the butterfly valve which will be bolted to the hinge. The lip of the piston will prevent the valve flaps from rotating the wrong direction. Two O Ring slots will be cut on the outside of the piston on a lathe. Buna N 4” O-Rings will be placed in the slots to prevent leakage around the sides of the piston.

The pump housing will be a 4” PVC Wye (45° Tee). A 4” Schedule 40 PVC cap will be placed on top of the wye to prevent flow coming out the top. A 4” band clamp from Diesel Supply will be purchased and used to fix the wye to the suction pipe of the units. This is necessary because the PVC wye and PVC suction pipe are both 4” Schedule 40. A 4” Schedule 40 internal coupling will be inserted into the bottom of the PVC suction pipe that will act as the lip for the check valve.

The shelter housing will be made from compressed earth blocks. Cement, sand, and/or gravel will need to be purchased for the blocks. In some cases, local earth may be used as some of the material. The amount of each material will be determined by location and local material availability. At this point, testing still needs to be performed to determine the ideal mixture for the blocks. If possible, more than one useable mixture will be determined so that there will be flexibility in constructing the blocks. The roofing structure will be made from corrugated sheet metal. The plastic bottle that will be installed into the roof can be any colorless, transparent bottle of 1-2 liters. As long as it is not damaged, smashed, or dirty, it can be used.

Manufacturing Considerations

Although most of the parts for our design will be purchased off the shelf, a few of the components must be machined or otherwise created. The major components that we will be manufacturing in-house are the piston, plunger handle, plunger bracket, valve flaps and the compressed earth blocks.

The piston will be machined from 4½ inch diameter aluminum round stock. The first step will be to turn the diameter down to 4.02 inches on a lathe. This will provide an appropriate surface finish allowing the piston to slide more easily. The next step is to cut the grooves for the O-rings. This can be achieved on the lathe as well using a square cutter. After sawing off roughly an inch long segment, I will face the workpiece to the proper length and mill out the pocket where the valve will be placed. In order to fixture the workpiece to the mill table v-blocks will be necessary due to the round cross-section. The pin hole can be drilled on a drill press paying careful attention to drill through the center of the piston wall.

The plunger handle will need to have a slot cut into it so that the main shaft of the plunger can be fastened to it. This can easily be achieved by using a grinder to create a flat surface at the midpoint of the ½ inch aluminum rod. Then a hole will need to be drilled through the center for the bolt to connect the handle and shaft. The shaft will also need to have holes drilled and threaded to match the ⅛ inch bolts which will hold the components of the plunger together.

The plunger bracket will be cut from .1 inch sheet metal aluminum. A hole will be drilled in the middle of the segment for the bolt that connects the piston to the plunger handle. This will then be bent at 90 degree angles using the sheet metal bender in order to properly form the bracket.

The valve flaps will also be cut from the .1 inch sheet aluminum. The cuts will be made using a laser cutter. Each set needs to be sized appropriately depending on whether it will be used for the piston butterfly valve or the check valve. Two holes will also need to be drilled in each flap matching the holes on the flat hinges.

Forming the compressed earth blocks will pose an interesting challenge. Since there are many possible dirt mixtures that can work with the block press, we will be doing some experimentation with various compounds of sand, clay, concrete and other earthy materials determine the most simple and easily replicable formula. The amount of water present in the mixture is also important to take into account. This process will be conducted using the compressed block press near the mechanical engineering building on campus.

The plastic bottle light requires a plastic bottle, a 10” x 10” piece of sheet metal, rubber sealant, bleach, and water. The bottle will be filled with bleach and water 1:200 ratio by volume. Rubber sealant will be applied to the cap and secured tightly to the bottle. A hole will be cut in the piece of sheet metal. Then short cuts on the edge of the hole will be made and the bottle pressed from the bottom to bend the tabs up securing the bottle. Rubber sealant will again be applied to the bottle and sheet metal to make the piece weather resistant. The last step is to fit the 10” x 10” piece of sheet metal to the roof with rubber sealant. If possible, water can be poured slowly on the piece after all the sealant has dried to identify any leaks that need to be sealed.

Figure 6. The water bottle light will be installed in a section of the corrugated roof

Looking to the future of this project beyond our involvement, we have several goals for what we would like to pass on to our sponsor. By the conclusion of our senior project we will provide our sponsor, Mr. Harish Bhutani, with complete bills of materials and manufacturing drawings (for the components which require additional processing) so that he has the ability to arrange for bulk production of our design. Mr. Bhutani has already built a distribution network in India through the course of his previous sanitation projects and it is our goal for him to use that in conjunction with our plans to implement more sustainable sanitation in rural India. In addition, we have connected with Indian non-governmental organizations (NGOs) with the intent of incorporating their resources as well to reach the greatest possible population of people in need. We purposefully have selected basic, common materials for our design to allow for even the least technically-trained citizens to be able to build and install a sanitation system in their village. The design's more complex manufactured parts are limited to the pump system which is intended to be made to order for those interesting and open to employment as waste collection personnel.

Safety Considerations

Water Bottle Light

The solution in the bottle will be 1 part bleach for 200 parts water. This means the water will not be safe to drink. While it is not expected that users will attempt to drink the water, the possibility must be considered. The bottle will be fixed to the sheet metal roof with rubber sealant and would be difficult to remove. If someone was determined, however, they would be able to remove it. At this point, the bottle would be difficult to open because the cap itself is sealed to the bottle. If the cap was removed or the bottle cut open, the taste of the first sip would almost certainly discourage further drinking. While the chances of somebody going through all this trouble to drink from the bottle are extremely unlikely, a warning label could be applied near the bottle that informs people that the water is not potable.

Gender Roles

Safety for women using public bathroom facilities has been a concern in India. In light of this fact, we have specifically designed the unit to be implemented for individual households. The ideal location of a toilet unit will be no more than a few feet from the residence of the user. This should encourage women to be more confident about using the facility during the darker hours of the day. Since many women limit their restroom usage to before dawn and after dusk, we have installed the water bottle light to provide limited visibility. In addition, the structure itself is robustly designed using the compressed earth blocks so the user will be physically safe within the unit. We have taken such precautions to preserve comfort and ensure safety to the users of the facility.

Eliminate Scavengers

Another safety issue that we have addressed with this design is the prominent existence of scavenging in the many communities in India. Not only is this practice extremely hazardous as it exposes the participant to raw human waste which contains infectious disease, but it is also illegal. To counteract this practice, we have limited access to the pit to only the two portals (from the squatting pan and through the suction pipe) and have devised a plan to employ citizens for collection duty. The collection squads will be trained to wear proper personal protective equipment and learn safe waste handling methods and protocols. Ideally this provides incentive for people currently acting as scavengers to take up a safer and more highly regarded profession. Access to the pits will be available to workers in the collection service but it will still be restricted to remain within the law.

Maintenance and Repair Considerations

Although the system is not necessarily meant to be completely permanent in nature, we have considered maintenance and repair throughout the design process. Low maintenance cost and overall ease of maintainability have been major goals for our project as they have been specifically stressed by our sponsor from day one. The stand-alone unit made for each residence has been designed so that very little maintenance is required to the everyday user. The shelter has been constructed simply and the system of waste storage is streamlined in such a way that basic cleanliness is the only concern to the end user.

The majority of maintenance considerations revolve around the simple design of the pump mechanism and the easy assembly and disassembly of the device. Beginning with the interface between the pump and latrine pipe coming from underground, the connection will be made with a simple four inch band clamp that is easily adjustable with the turn of a couple hex nuts. This will facilitate quick and easy connection while also forming a strong hold on the two components. The handle for the pump is assembled using ⅛ inch hex bolts. Since the top cap on the pump is located between the handle and bracket, the bolts allow for complete disassembly of the piston from the pump pipe. If any part of the plunger is broken or faulty it can be easily removed and replaced. The only part of the pump with any significant complexity is the piston which has been designed to be the most robust component. Every other part, from the valve flaps to the valve pin and O-rings can be accessed with the turning of a few standard hex bolts. The tolerances between the piston's O-rings and the pipe are designed such that the piston can be removed smoothly.

Although pump repair is unlikely, care has been taken to ensure that all components (barring perhaps the piston/bracket) are standard off-the-shelf parts readily accessible within a reasonable distance from the end user. More likely, disassembly and reassembly will be required for regular cleansing of the system. Due to the consistent use of fasteners, only a single crescent wrench will be required for complete dismantling of the pump. All components are corrosion proof (due to their material properties addressed in the *Material, Geometry and Component Selection* section) meaning that cleaning will not present any compromise to the product.

In the event of the pipe clogging at the check valve, the entire pipe section can be carefully removed from the latrine pit. While this is an unlikely situation, the check valve at the bottom of the pipe can also be simply removed due to our use of consistent fasteners. We recommend that this be performed only by trained collection professionals who are properly dressed to handle the dirty components.

Maintenance costs are also an important aspect of the final product. As the initial plan is for collection to occur once every six months, with a maximum of five plastic collection barrels per unit, annual collection costs total only about $100 per unit according to Wateraid estimates which is slightly above our goal but is significantly offset due to the potential business model we have suggested for waste collection.

Design Verification Plan

Testing

Pipe Corrosion
The pH of urine varies between 4.6 and 8 among individuals. Because the collection will be the aggregate waste of many individuals it is safe to assume that the resulting pH will always be within that range. The pH of stool varies between 7 and 7.5 so it is still safe to assume a minimum pH of 4.6 and maximum pH of 8. To test the materials for corrosion, they will be placed in solutions whose pH will be either side of the range. In total there will be 8 tests run simultaneously. Aluminum, PVC, CPVC, and the O Rings will be placed in a solution with a pH of 4.6 and in a solution with a pH of 8. This ensures that all the materials are tested for the pH extremes. CPVC which is similar to PVC will also be tested to see how well it handles so that it can be considered as a material option. To run the tests, bleach, hydrochloric acid, and pH test strips will be purchased. The bleach and hydrochloric acid will be mixed with water until the required pH is attained. Austen will take the necessary materials home for summer and perform the test. This will allow for routine observations to be taken up until the end summer.

Lighting Effectiveness
In order to test the bottle lighting method, we want to conduct a test to see what mixture of water and disinfectant allows for the most visibility without compromising the effects of molding and bacteria. We will test various solutions of water and chlorine and water and bleach. The key aspect will be how light intensity. We will also conduct tests both in varying amounts of sunlight and moonlight to see the effects of different lighting conditions on the output of the water bottle light.

Collection Pit Strength
The goal of this test will be to see how a real concrete pit withstands the forces of the earth around it. Due to the complexity of mixing the concrete in large quantities and moving a large cylindrical concrete pit we will be using a scaled down model. Although this will not perfectly represent the final design, it will allow us to get a good reading of the feasibility of the design. This test functions more as a way of confirming some of the calculations we made regarding the strength and rigidity of the pit. We will mix concrete for a one-third scale pit and dig a hole in the ground. After placing the pit in the ground we will see how the surrounding earth contributes to stresses on the cylinder. In addition we will conduct tests with a slurry inside of the pit. Although this will most likely counteract the outside forces to some extent, we wish to see how well the pit holds up.

Valve Leakage

The valve leakage test requires us to have a functioning early prototype of the piston and butterfly valve as well as the check valve. While this test will be a way of evaluating the current design, it will also serve as a trial and error process for our valve effectiveness. The plan is to place the initial plunger assembly in a section of four inch PVC pipe and fill the top with a mixture with a slurry-like consistency. Results will be determined by the amount of leakage while the piston remains stationary as well as the piston in motion. The valve flaps must lie flat enough on the piston ridge and the O-rings need to seal well enough for little to no leakage to occur. A similar test will be conducted using the initial prototype of the check valve. Since the check valve will remain fixed with relation to the suction pipe, only a stationary leakage test needs to be conducted. This test will essentially be evaluating the effectiveness of the O-rings, the valve flaps (both on top and bottom) and the smoothness of motion between the plunger piston and the wall of the suction pipe and pump housing.

Bracket Strength

The ultimate tensile strength of aluminum is 45,000psi and its yield strength is 40,000psi. The stress in the bracket must not exceed 45,000psi or it will fail and can't exceed 40,000psi or it will undergo plastic deformation. Calculations suggest that with a cross section of ¼" x ¼", the bracket will not fail assuming a 30lbf load from the shaft. We would like to test this as certain assumptions were made such as modeling the bracket as a simple beam. A tensile testing machine will be used to pull on the shaft and piston. The amount of force required for failure and the failure location will be recorded. Also, any areas that undergo plastic deformation before failure will be recorded. A failure force of 50 lb_f or greater will be considered acceptable. A force less than this will be sufficient reason to consider redesign of the bracket.

Table 4. DVP&R for Planned Tests

Design Verification Plan and Report													
Date	3/11/2014		Sponsor	Harish Bhutani						Team	Cal Poly India Project		
TEST PLAN										TEST REPORT			
Item No	Specification or Clause	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES TESTED Quantity	SAMPLES TESTED Type	TIMING Start date	TIMING Finish date	TEST RESULTS Test Result	TEST RESULTS Quantity Pass	TEST RESULTS Quantity Fail	NOTES
1	Safety	Structure Material Failure	Holds rigidity	Derek	DV	5	CEB	9/29/2014	9/29/2014				
2	Materials	Accelerated Pump Pipe Corrosion	3 months w/o corrosion	Alex	DV	1	PVC	6/10/2014	9/25/2014				
						1	CPVC						
						1	Aluminum						
						1	O-rings						
3	Materials	Collection Pit Strength	No collapse of wall	Austen	DV	1	Concrete	10/22/2014	10/29/2014				
4	Safety	Lighting Effectiveness	Room brightness	Derek	DV	1	Chlorinated	10/20/2014	10/20/2014				
						1	Bleach						
5	Functionality	Valve Leakage	Little to no leakage	Alex	DV	1	Piston	10/26/2014	10/26/2014				
						1	Check						
6	Functionality	Bracket Strength	>50 lb force	Austen	DV	3	Sheet Metal	10/22/2014	10/22/2014				
7	Materials	Roof Material Permeability	No leakage	Derek	DV	1	Corrugated	11/1/2014	11/4/2014				

Product Realization

Manufacturing

The manufacturing phase brought with it many complications which, upon being addressed, allowed for small, yet significant, improvements to be made in the final design. This phase of the prototype realization faced some limitations which would ideally be able to avoid in larger production runs but allowed us to consider the differences between this early prototype stage and a potential mass manufacturing run.

Pump

The pump manufacturing began with simply marking up the pipe and cutting each piece to length. The pipe which will hold the check valve has a 17/64” hole drilled directly through the center located above the lower pipe fitting by 2” to account for the fitting within the pipe and the flaps below the valve pin. We milled two 1-½” slots in the bottom of the lower pipe fitting to allow for the flow of larger pieces of waste while preventing clogging.

Figure 7. The lower pipe fitting has slots to allow for proper flow regardless of the position in the pit

The most complex subassembly was the piston in that it contains the most parts and also requires the tightest tolerances. The main butterfly valve housing (or piston) was cut with a horizontal saw to length and then the diameter was turned down on a lathe to match the inner diameter of the pipe. Since the pipe was not actually the nominal size expected for the Schedule 40 designation, we had to tweak our dimensions to match the real dimensions of the pipe.

Figure 8. A horizontal saw is used to cut the stock aluminum round to length

The counterbore in piston was cut using a boring bar on a manual lathe. We started by drilling increasingly large holes in center of the round aluminum. Then, using the boring bar, we turned from the inside of the round out to extent of the open through hole. Then, setting a stop to limit the z-direction feed, we turned out the counterbore with the boring bar. The next step with the piston is to drill the 13/64" through hole on one side and a size G through hole on the other. The side with the 13/64" hole is then tapped with ¼"-20 internal threads to account for the hinge/valve pin. For the prototype we opted against machining the cylindrical slot for the o-rings in order to cut back on manufacturing processes and o-ring cost. This was also partially due to the fact that potentially varying pipe and piston sizes could require varying slot and o-ring sizes. In testing we were able to verify the lack of necessity of the o-rings.

Figure 9. The piston counterbore was turned on the mill using a boring bar

The butterfly valve construction was altered significantly from what would occur in a full production run but the outcome yields essentially the same product. To cut out the valve flaps we used a laser cutter programmed with the correct diameter. While this method was relatively quick and simple, we do not want to assume the availability of laser cutters for all of our clients. In addition, the machine we used was limited in the materials it could cut forcing us to use thin steel instead of the aluminum we specified during the design phase. In a larger manufacturing setting we would use a die punch system and be able to use aluminum. This would be much cheaper, since a large production run can offset the initial cost of the die, and more reliable, as the aluminum will not rust or corrode as the steel will. For the valve pin, we cut the ¼” rod to a length just within the outer dimensions of the piston. On one side, we tapped the rod with external ¼”-20 threads to fit into the piston housing. On the opposite end of the pin we chiseled in a small slot so that the pin can be inserted or removed from the piston housing with a flathead screwdriver.

Figure 10. The valve flaps were laser cut for the prototype but would be punched with a custom die in a full production run

The hinges for the valve were a purchased item although they needed to be shortened in order to fit in the piston counterbore. Each hinge was cut with the horizontal saw and ground down on belt sanders to create the appropriate fit. The flaps for the check valve were cut in the same way as the butterfly valve using the laser cutter but the hinges did not need to cut as the full pipe diameter could accommodate their size. The corners of the hinges were still ground to avoid interference during pumping. The pin holding the check valve in place was cut from ¼” rod and each end was tapped with ¼”-20 external threads to allow for fastening the valve together during assembly.

Figure 11. The check valve pin inserted in the hinge

The handle and plunger rod required very little manufacturing processes. For the handle, we cut the rod to length and drilled a 17/64" through hole through the middle. We milled out a small pocket over the hole to provide a flat surface for the plunger rod to sit upon. The plunger rod was cut to length and then 13/64" holes were drilled one inch deep into each end. The holes were then tapped with ¼"-20 internal threads.

The bracket was formed from a 1" x 1/8" aluminum strip sheared to length. In the center of the bracket a 17/64" hole was drilled for the connection to the plunger rod during assembly. The final step was bending the bracket's right angles on the press break.

Structure

The shelter is composed of two major components, the roof and the compressed earth blocks. For the prototype we started from scratch but these could be easily produced to add on to an existing building.

The roof is cut out of corrugated sheet metal to fit the dimensions of the shelter which can vary but was 5' x 5' for our prototype. A small square hole is cut in the middle of the sheet using tin snips. This hole only needs to be slightly larger than the water bottle diameter on each side. Since the water bottle light may be added to an existing roof or may be built into a new one, it is best to make a separate section of roof in which the bottle is secured. This piece needs to be at least two inches larger in length and width than the square hole in the main roof section. In the center of this smaller piece of corrugated metal, we punched a small hole using a hammer and circular chisel. We then used circular punch die sets to increase the hole size to accommodate the water bottle. After reaching a hole size slightly smaller than the water bottle diameter we used a hammer and chisel to make tabs around the circle approximately ½" wide. These were bent upward to provide a tight fit for the water bottle to sit.

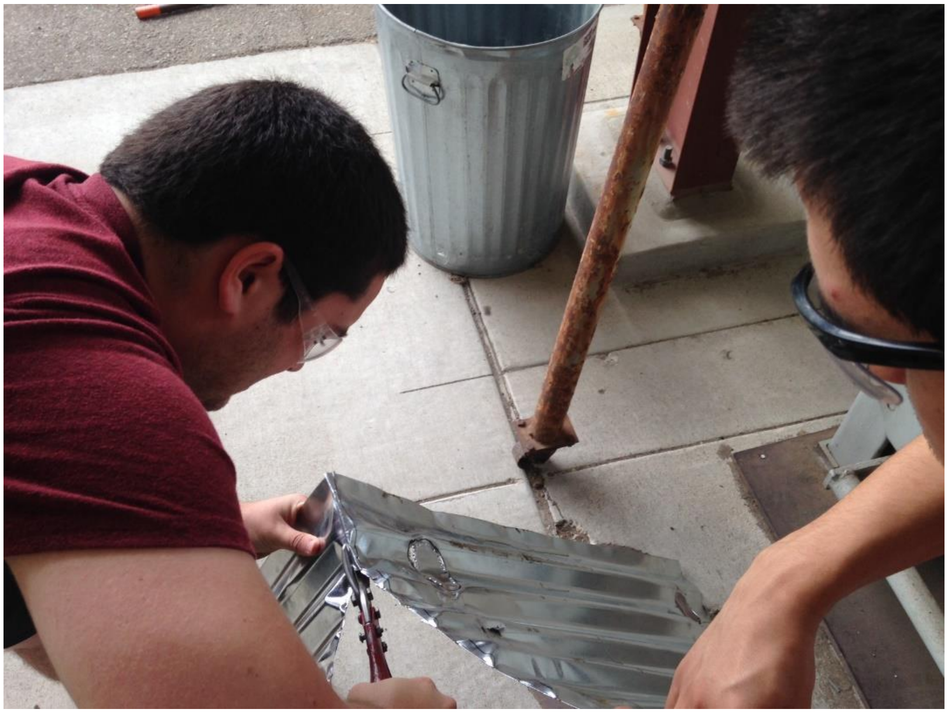


Figure 12. The hole for the water bottle was cut using a circular punch and tabs were formed using a hammer and chisel

The compressed earth blocks were formed using a large block press. The dirt mixture was provided by the civil engineering department but was essentially a combination of soil, clay, sand and a small amount of cement. After thoroughly mixing in enough water to make the earth damp to the touch, we weighed out seven pounds of the mixture and placed it in the press making sure to compress the earth by hand to identify areas needing to be filled more sufficiently. The next step was to close the lid and pull the bar over the press which utilizes a linkage system to compress the earth.

Assembly

Pump

The assembly of the pump was designed to be simple, require a minimal amount of tools and use standard parts. Although the prototype was built using English units and Standard English sized parts and fasteners, the design can be easily modified for foreign markets and metric unit systems. Our intention is that the product is designed and even built in English standard with perhaps only fasteners (or any part that is used in assembly/disassembly) in metric so that the maintenance crews can use standard sized tools when working with the product. Regardless, all that is necessary for assembly is a flathead screwdriver, a crescent wrench and perhaps a soft mallet.

Assembly of the pump starts with the mostly submerged portion of pipe. The first step is to place the check valve flaps in the bottom of the pipe aligned with the hole for the pin and the hinge side facing the longer end (top) of the pipe. The double threaded pin is placed through the hole and fastened together with a flat washer and a ¼”-20 nut on each side. The key with tightening these nuts is in balancing securing the assembly together firmly and leaving room for the flaps to freely rotate. An issue we encountered during final assembly was that when we tightened the nuts too much, the check valve was rendered nearly immovable, crippling the performance of the pump. The next step is to place the lower pipe fitting (with the two slots) on the bottom of the long pipe section. This will provide a surface for the check valve flaps to sit on during inactivity and the down stroke of the pump.

Figure 13. This picture shows how the check valve should be assembled. We used tape to indicate which flap belonged on which side. This was a result of alterations that needed to be made to the flaps due to nonuniform pipe diameter.

The upper section of the pump is assembled using the wye-piece pipe, cap, two short sections of pipe, the band clamp, the piston, the plunger and handle, butterfly valve flaps and butterfly valve pin, bracket along with ¼”-20 bolts and nuts and ¼” lock washers. For initial assembly it is easiest to place the butterfly valve flaps in the piston before attaching the bracket. To do so, aligned the flaps in the counterbore of the piston such that the hinge holes are lined up with the holes in the piston outer wall. Insert the valve pin threaded end first into the through hole and screw it into the threaded end using a flathead screwdriver in the chiseled slot on the opposite end of the pin. The flaps should rotate freely up and rest nicely on the counterbore ledge. The next step is to TIG weld the bracket onto the top ring of the piston. If part of the weld bead sits outside of the outer radius of the piston you may need to file or grind off some of the excess weld to permit smooth travel of the piston through the pipe. After attaching the bracket, use a ¼”-20 bolt to attach the plunger rod to the bracket through the hole in the bracket and in the internal threads of the plunger. Before attaching the handle, it is advantageous to place the piston in the wye-piece pipe such that the plunger extends out of the bottom branch of the “Y” (or the top of the pump chamber). Then attach one small section of pipe to the top and bottom of the wye-piece pipe. It may be necessary to use a soft hammer to make sure the pipe is fully inserted into the wye. Place the cap on the upper end of the pump so that the plunger rod fits through the hole in the cap. Now fasten the handle to the plunger using a ¼”-20 bolt through the threads in the plunger. The plunger rod should sit in the slot on the handle. The last step in assembly of the upper pump is attaching the band clamp firmly to the bottom small pipe section. This requires a flathead screwdriver and should be tightened firmly as this end of the band clamp will rarely need to be removed. A tip for ease of use in the field is to position the band clamp halfway on the pipe so that the lower pipe section will be inserted into the bottom half of the band clamp.

Structure

When assembling the roof there are many options for adhesives. A watertight caulk, rubber cement or gorilla glue equivalent will do nicely. First place the water bottle in the hole of the small section of corrugated metal roofing. This will require you to slightly bend the tabs outward to fit the bottle properly. Take care not to puncture the water bottle and insert the bottle such that the cap is facing the opposite direction that the tabs were bent. Use an adhesive to secure the bottle more firmly and avoid shifting which can result in water bottle leaks. Then attach the small section of roofing on the main panel so that the cap faces upward. Again use the adhesive to seal and gaps between the roof sections and the water bottle.

Figure 14. Caulk is applied to create a watertight seal and secure the water bottle light in the roof section

The compressed earth blocks are assembled together in an overlapping pattern for stability. To ensure straight and consistent stacks it can be helpful to place a rod of some sort (commonly a bamboo pole in Thailand where the blocks are currently being used) in the holes of the blocks. This is not necessary in every hole but it can be good every few blocks and especially on the corners. The rods can be removed post-construction or left inside to act as a sort of rebar.

Product Validation

Pump Suction Test

The prototype of the pump was completed during the end of October but was not ready for testing. The flaps on both valves were having clearance issues and contacting the piston and pipe walls. This issue was fixed by iteratively filing the flaps and reassembling the valves to check the clearances. Two of the bolts holding the flaps were cut shorter so they would not contact the bottom of the piston as the flaps rotated.

The pump was then tested at the Poly Canyon Village swimming pool on November 4th, 2014. Initially water was not pumped but more attempts were made. The pump was disassembled and all nuts and seals were tightened. The pump was then tested in deep water where it worked. This was expected because the piston would begin underwater so it was tested in shallower water at the pool steps. The pump worked here meaning the pump can be primed without the piston being submerged.

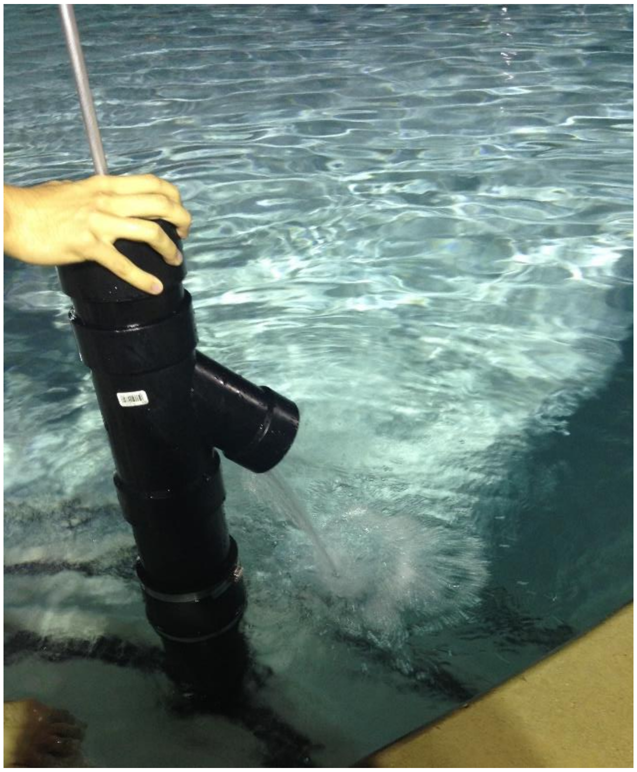


Figure 15. Pump test in PCV pool

Austen took the pump back to his apartment where he tightened nuts that had loosened during testing. He then demonstrated the pump to his roommates and friends in the bathtub. It worked again and Rubia was able to operate the pump even though she has a very small build.

Derek and Alex tested the pump with a longer section of pipe at varying water depths to see the distance between the piston and water level at which the pump could still be primed. After multiple attempts gradually increasing depth, the determined that the distance was 8in. This is not an issue because pumping will begin with the piston submerged which means the user will not have to prime the pump. The fact that the pump can be primed when the piston is not submerged but within 8 inches of the fluid level is beneficial. Being able to prime the pump when the piston is not submerged helps because a pit that is not quite at full capacity (with an unsubmerged piston) can still be pumped in the event that personnel are already in the area to work.

Lighting Effectiveness Test

The roof was tested by placing it on a tall cardboard box to simulate the earth block structure. Small tears in the box were sealed with duct tape. A black sheet was draped over the roof and structure to limit incoming. Only a small hole was left in the sheet to allow the water bottle to collect sunlight. A small rectangle (≈ 1” by 5”) was cut in the side of the box to observe inside. The sheet hung far enough that you could look in while staying underneath the sheet. Testing was done on an overcast day and the light was still successful. Looking in you could see light coming into the structure through the water bottle but unwanted light was also coming in through the sheet and grooves in the corrugated sheet metal. To overcome this, Derek and Alex put the entire box over Austen and added covering to the sheet metal with their jackets. They initially covered the water bottle as well and Austen confirmed that there was no light entering. Then they allowed light only through the water bottle. After some adaptation, there was comfortable visibility within the structure. As long as you do not stare directly at the water bottle light, your eyes adjust such that you see everything within the structure. Alex and Derek both had the same results when they went inside the box.

Figure 16. Roofing structure and light

A few modifications were made to the mock structure for demonstration at the expo. Compressed earth blocks were printed on the plotter and attached to the cardboard for aesthetic appeal. Duct Tape was used to prevent light entering the structure since laying jackets over would be a sloppy method for the expo. The box flaps were taped to the sheet metal and any remaining gaps were sealed with tape. The sheet remained so that people would not let light into the structure while they observed through the slit. It was dark and overcast during the expo, but we were able to demonstrate the concept by using lights on our phones to illuminate the bottle from the outside while they looked in. Also packing foam was taped to the corners of the sheet metal to avoid injury.

Bracket Tensile Test

A tensile test was done on the bracket material because the bracket is the highest risk component of the pump. It is the component with the smallest cross section undergoing stress caused from pumping. The aluminum with a cross section of 1” by ⅛” failed at 4350lbf. This is an ultimate tensile strength of 35ksi while Aluminum 6061 has an ultimate tensile strength of 45ksi. This shows that the tensile test was an important test to run so that 45ksi wasn’t assumed. Reasons for the actual ultimate tensile strength may be that the aluminum may be a different alloy altogether. Previous stress calculations show that 35ksi will never be reached. The pump would not be operable at this point anyway because no single person could apply a force great enough to reach 35ksi.

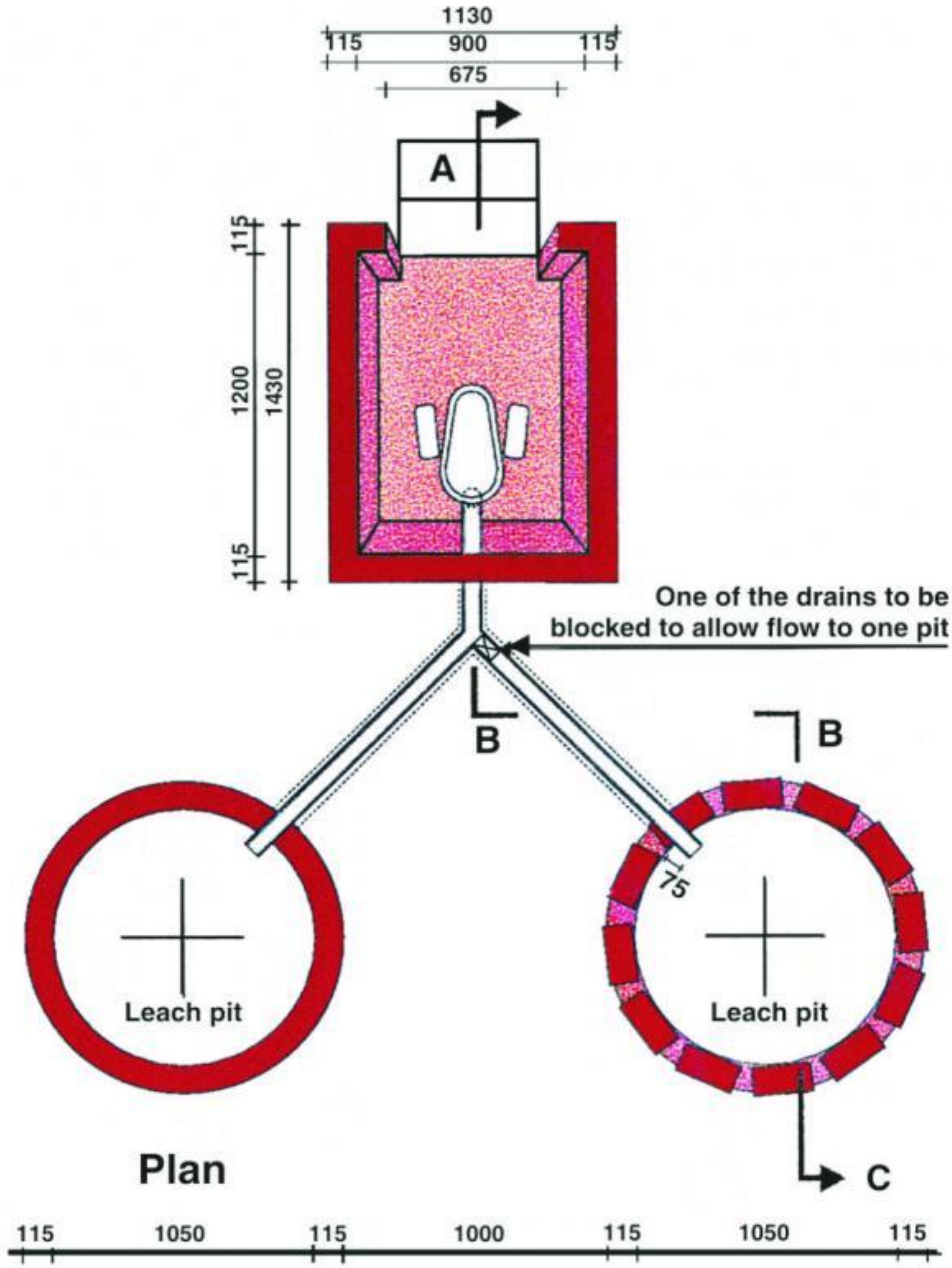
Figure 17. From left to right: bracket dimensions, tensile test setup, broken cross section

Conclusions and Recommendations

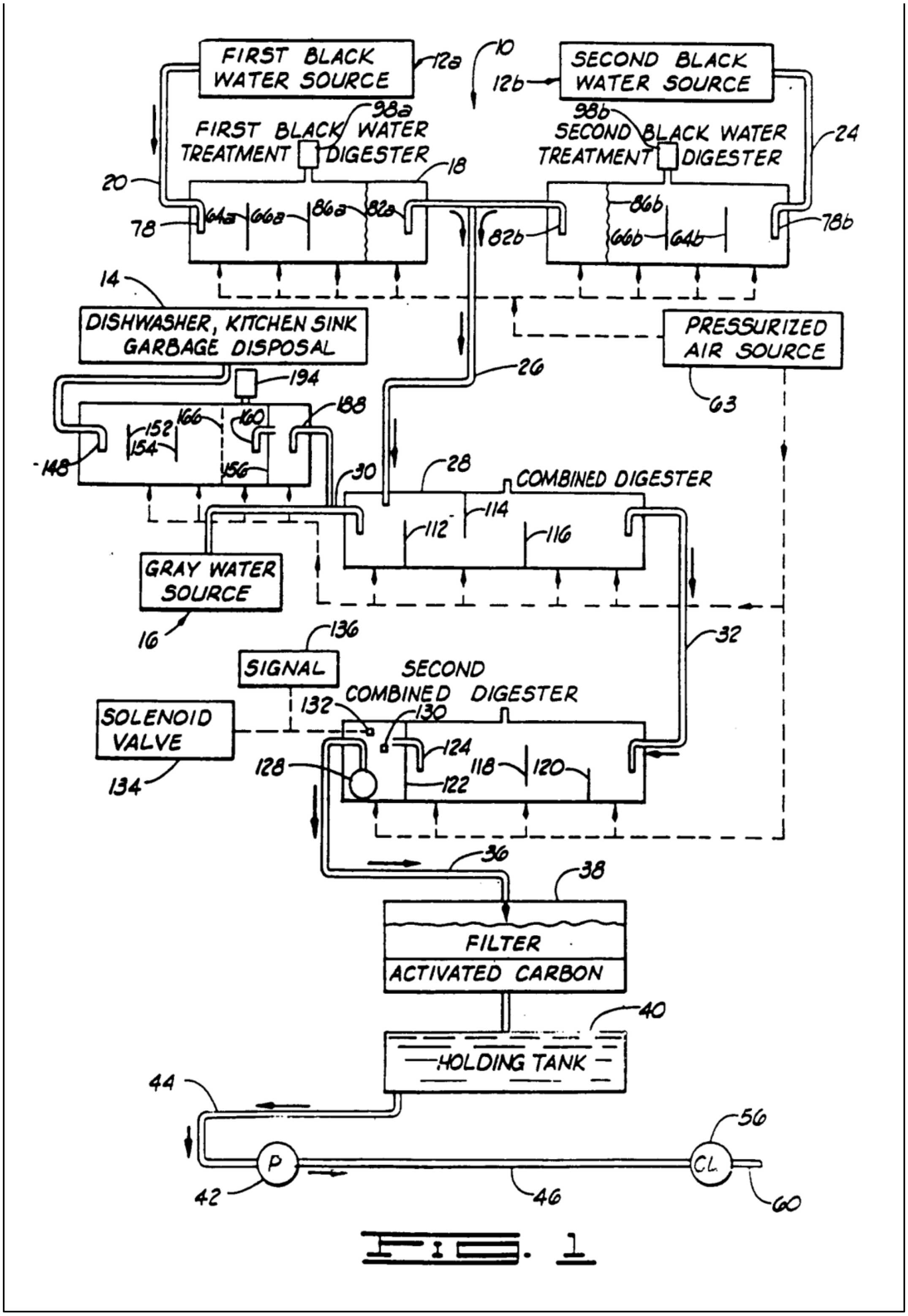
The design of this project employs a low-cost, easily manufactured, and safe design for a waste disposal system. The main constraints that led to our design were the environmental condition of the case study we were observing, as well as the cultural traditions of the people of India. Our goal is to have a design that can respect the taboos of Indian norms, but still cater to the general engineering necessities that transcend a specific culture so that this design will meet the needs of other rural areas globally. This is where the design of a pit latrine with a hand pump became the best choice for solving the original problem. The concrete itself is an ideal protector from harmful bacteria into groundwater, and the pit is easy to manufacture. The shelter is sturdy enough to withstand large amounts of external force, but it can be easily taken down for repairs or relocation. The pumping system, when considering the testing and the proof of concept, will be easily integrated into both the physical layout of a village as well as the cultural side of a village. The system is low impact and has the durability to last for a long time. The final goal is to create an infrastructure that can create jobs for the people in the area. The research that was done in the preliminary stages showed that the success of a project will hinge on the perceived benefits of a system that is being established. Having someone outside of the village come in every six months to clean the pit will provide a person with money for the job, and the villagers will be more likely to enjoy the benefits of no maintenance on the system and the improved conditions of the water. Since there are so many existing designs for sustainable sanitation systems the goal is really to make the most suitable and reliable system without running up construction or maintenance costs too severely. Our design is specifically aimed to address the faults of the existing two-pit system and other pit latrines that create more of a problem than they solve. We understand that even the perfect product can be useless if it is not embraced by the community so we have devised a system that involves the local community in the production and maintenance of the product. The long-term goal is to partner with a non-profit so that our simple and effective design can be paired with an educational campaign that will open the eyes of these countries in need and encourage their citizens to work towards their own physical and social betterment.

For this sanitation system to work, there needs to be a framework established in order to have the needs of the design met. One key step that needs to be taken before any development or planning can occur is a sanitation education program. The reason for this is because often times the connections between hazardous sanitation practices and the presence of fecal-borne disease aren’t made so clearly. Knowledge of the dangers of bacteria and what a good waste management system can do to prevent illnesses will be important to aid the villagers in having a good reception towards having this project put in place. Once a program like this is set in place, another recommendation would be to have NGO’s and other humanitarian efforts work closely with the village and the manufacturing plants in order to oversee a smooth transition to having this toilet built in the households. This supervision can take a few years before the villagers could be confident enough to use the system and be able to care for it. As for the technical aspects, one suggestion to heed is having spare parts already manufactured and ready to replace failed components when necessary. This system is built for a good longevity, however, this prototype has not been tested in conditions similar to Indian regions. It would be good to be prepare for any foreseeable problems. Additionally, the workers who will be handling these pumps should be warned of the potential dangers of accidental exposure or ingestion of the slurry; this will prevent illness and spread of diseases. They should also be well informed on the basic operating mechanics of the pumping system in order to make necessary modifications to the parts. For this design, modifications to the check valve flaps could be needed because of the tendencies for the bolts on the outside of the pipe to be over tightened. Certain modifications to the piston can be made; for instance, the prototype didn't have o-rings because the size changes in the diameter created a good suction for the fluid to be pumped out of the pit. Finally, this design is meant to be a universal system that doesn't have to be restricted to a certain region. Cosmetic changes, as well as function modifications are encouraged as long as they do not hinder the basic functionality of the shelter, lighting system and the pump.

Appendix A – References



Top-down view of Sulabh International Two-Pit System design



Patent for multiple stage sanitation system that implements black and combined treatment digesters

TABLE I - DIGESTER SOLIDS REDUCTION VALUES

FIRST BLACK WATER TREATMENT DIGESTER 18

	Inlet to First Black Water Treatment Digester 18	Outlet of First Black Water Treatment Digester 18
Time A	13,800 mg/l	990 mg/l
Time B	9,600 mg/l	260 mg/l
Time C	2,500 mg/l	280 mg/l
Time D	2,500 mg/l	160 mg/l

SECOND BLACK WATER TREATMENT DIGESTER 22

	Inlet to Second Black Water Treatment Digester 22	Outlet of Second Black Water Treatment Digester 22
Time A	9,900 mg/l	550 mg/l
Time B	3,100 mg/l	160 mg/l
Time C	7,000 mg/l	240 mg/l
Time D	3,800 mg/l	200 mg/l

COMBINED DIGESTER 28

	Inlet to Combined Digester 28	Outlet of Combined Digester 28
Time A	3,150 mg/l	no count taken
Time B	13,600 mg/l	11,000 mg/l
Time C	2,400 mg/l	140 mg/l
Time D	500 mg/l	140 mg/l

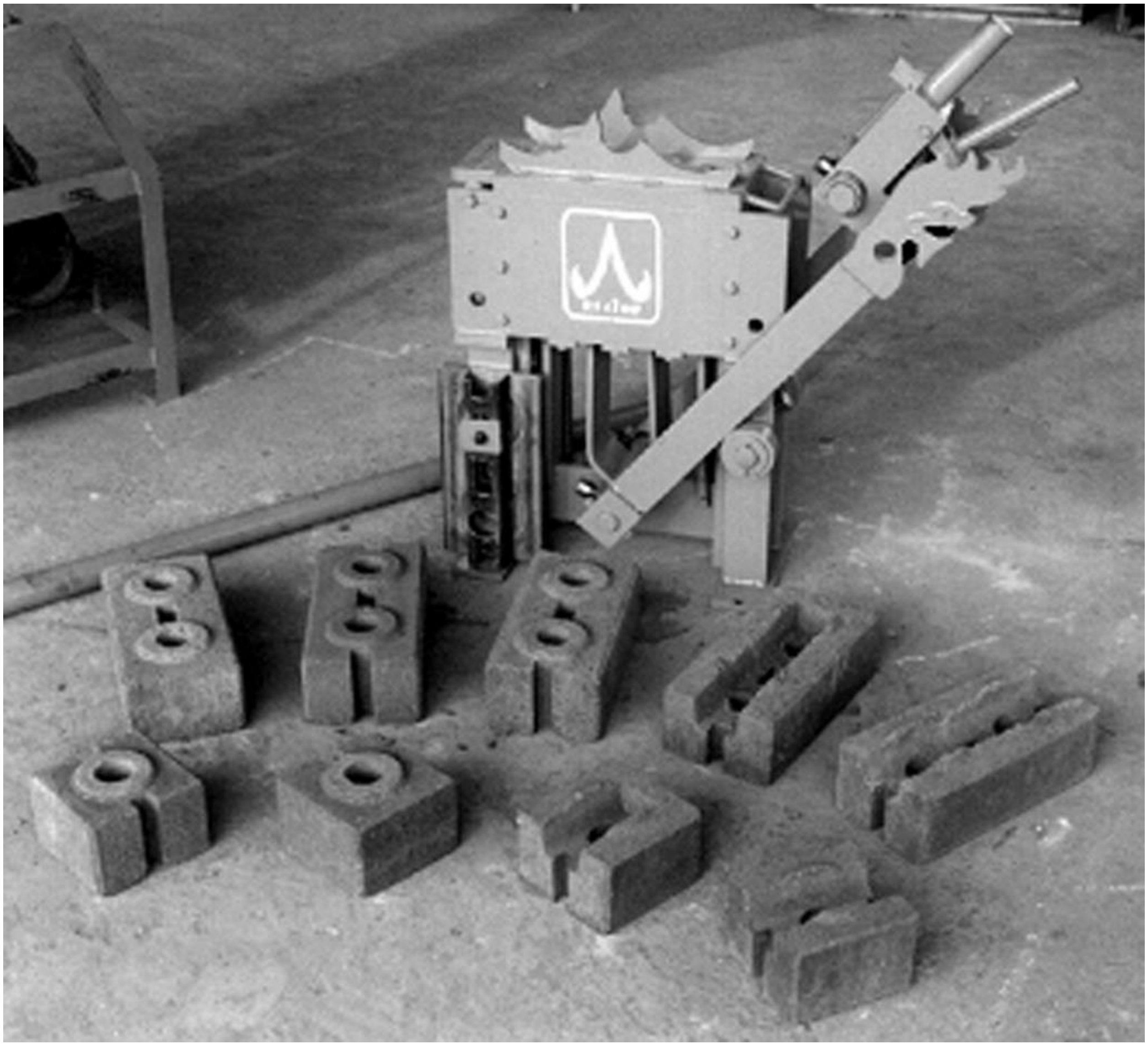
SECOND COMBINED DIGESTER 34

	Inlet to Second Combined Digester 34	Outlet of Second Combined Digester 34
Time A	17,600 mg/l	60 mg/l
Time B	8,700 mg/l	80 mg/l
Time C	80 mg/l	70 mg/l
Time D	90 mg/l	80 mg/l

FILTER 38 DISCHARGE

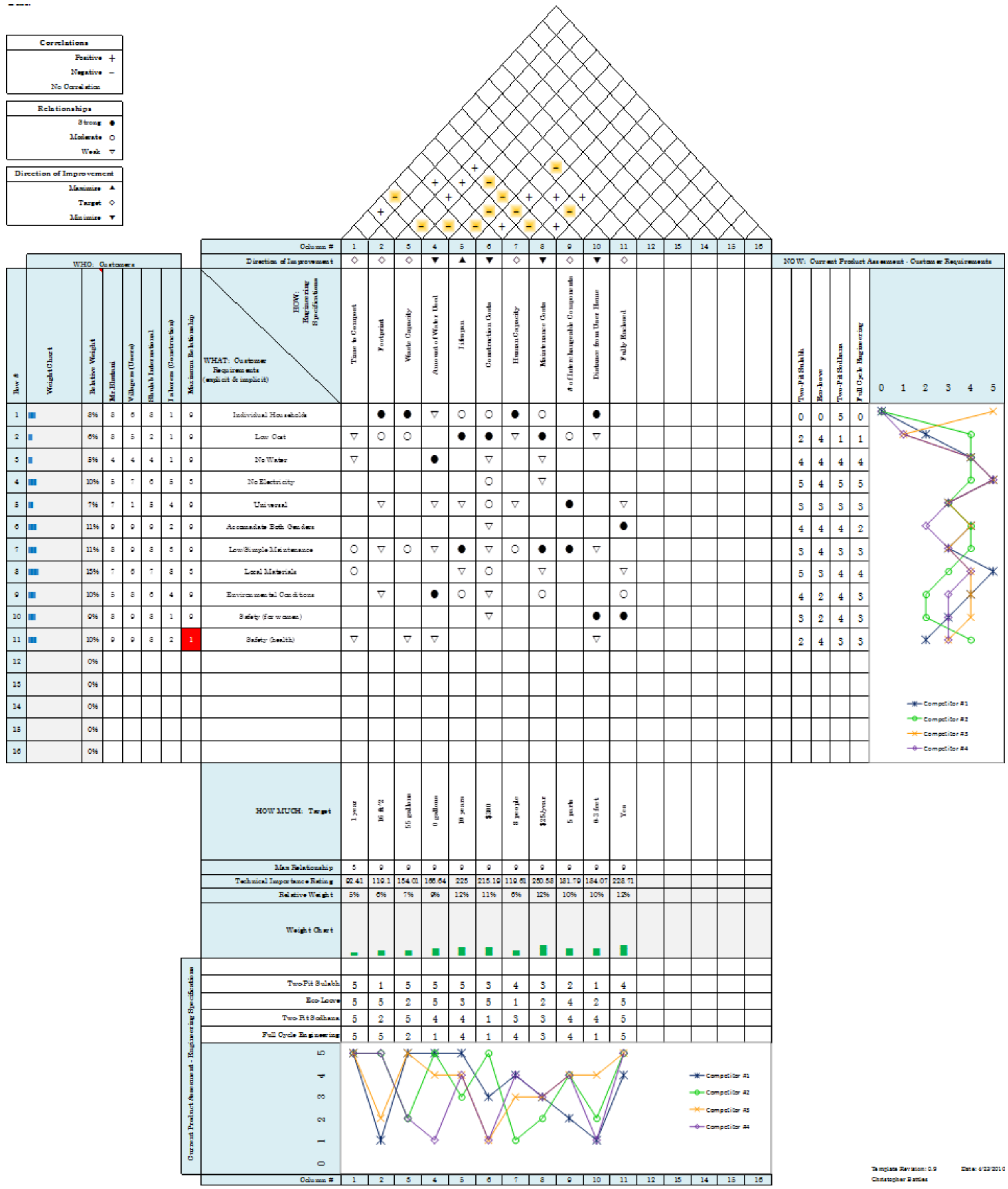
Time A	60 mg/l
Time B	80 mg/l
Time C	60 mg/l
Time D	60 mg/l

Data for amount of suspended solids at four times for various stages of the black and combined treatment digester system



Compressed earth block press for making interlocking bricks

Appendix B – Design Development Figures



House of Quality, modeled to weigh out the specifications, needs, and how competing designs measure up to the goals of this project.

Eliminate Waste									
Criteria \ Concept	Datum	Solar Reflector	Bacteria	Compost	Dump Into Water	Throw In Ditch	Convert Into Fuel	Burn	Compact
Individual Households	0	0	0	0	0	0	0	0	0
Low Cost	0	-	0	0	0	0	0	0	0
No Water	0	0	0	0	0	0	0	0	0
No Electricity	0	0	0	0	0	0	0	0	0
Universal	0	0	0	0	0	0	0	0	0
Accomadate Both Genders	0	0	0	0	0	0	0	0	0
Low/Simple Maintenance	0	0	0	0	0	0	0	0	0
Local Materials	0	-	0	0	0	0	0	0	0
Environmental Conditions	0	+	+	+	-	-	+	-	0
Safety (for women)	0	0	0	0	-	0	0	0	0
Safety (health)	0	+	0	0	-	-	0	0	0
Sum +'s	0	2	1	1	0	0	1	0	0
Sum 0's	0	7	10	10	8	9	10	10	11
Sum -'s	0	2	0	0	3	2	0	1	0
Net Score	0	0	1	1	-3	-2	1	-1	0
Continue?	n	y	y	y	n	n	y	y	n

Pugh Matrix for "Eliminate Waste" evaluating each concept against the customer requirements

Eliminate Waste								
Design Criteria / Weighting Factor / Alternatives	Individual Households	Low Cost	Universal	Low/Simple Maintenance	Environmental Conditions	Safety (Women)	Safety (Health)	Sum
	0.05	0.24	0.10	0.19	0.14	0.14	0.14	1.00
Datum	10% / 0.5	10% / 2.4	15% / 1.5	15% / 2.85	10% / 1.4	17% / 2.38	10% / 1.4	12.43
Solar Reflector	10% / 0.5	13% / 3.12	13% / 1.3	17% / 3.23	20% / 2.8	17% / 2.38	26% / 3.64	16.97
Bacteria	20% / 1.0	15% / 3.6	19% / 1.9	16% / 3.04	21% / 2.94	17% / 2.38	23% / 3.22	18.08
Compost	20% / 1.0	18% / 4.32	18% / 1.8	14% / 2.66	21% / 2.94	17% / 2.38	23% / 3.22	18.32
Convert Into Fuel	20% / 1.0	19% / 4.56	14% / 1.4	13% / 2.47	25% / 3.5	16% / 2.24	15% / 2.1	17.27
Burn	20% / 1.0	25% / 6.0	21% / 2.1	25% / 4.75	3% / 0.42	16% / 2.24	3% / 0.42	16.93

Weighted Decision Matrix for "Eliminate Waste" evaluating each concept against the customer requirements taking into account relative weight of requirements

Shelter User									
Criteria \ Concept	Datum	Tent	Basement Structure	Outhouse	Platic Bubble	Trees	Cardboard Box	Compressed Earth Blocks	Cliffside
Individual Households	0	0	0	+	0	0	+	0	-
Low Cost	0	0	0	0	0	0	0	0	0
No Water	0	0	0	0	0	0	0	0	0
No Electricity	0	0	0	0	0	0	0	0	0
Universal	0	0	0	0	0	0	0	0	0
Accomadate Both Genders	0	0	0	0	0	0	0	0	0
Low/Simple Maintenance	0	0	0	0	0	+	0	0	0
Local Materials	0	0	0	0	0	+	+	0	0
Environmental Conditions	0	-	0	0	0	+	-	0	-
Safety (for women)	0	0	0	0	-	-	-	0	0
Safety (health)	0	0	0	0	0	0	0	0	0
Sum +'s	0	0	0	1	0	3	2	0	0
Sum 0's	0	10	11	10	10	7	7	11	9
Sum -'s	0	1	0	0	1	1	2	0	2
Net Score	0	-1	0	1	-1	2	0	0	-2
Continue?	n	n	n	y	n	y	n	y	n

Pugh Matrix for "Shelter User" evaluating each concept against the customer requirements

Store Waste									
Design Criteria / Weighting Factor / Alternatives	Individual Households	Low Cost	Universal	Accommodate Both Gender	Low/Simple Maintenance	Local Materials	Environmental Conditions	Safety (Women)	Sum
	0.04	0.19	0.08	0.14	0.18	0.11	0.11	0.15	1.00
Datum	20% / 0.8	10% / 1.9	25% / 2.0	25% / 3.5	20% / 3.6	15% / 1.6	30% / 3.3	28% / 4.2	20.9
Outhouse	40% / 1.6	30% / 5.7	28% / 2.24	25% / 3.5	20% / 3.6	20% / 2.2	30% / 3.3	27% / 4.05	26.19
Trees	5% / 0.2	40% / 7.6	26% / 2.08	25% / 3.5	40% / 7.2	30% / 3.3	5% / 0.55	5% / 0.75	25.18
Compressed Earth Blocks	35% / 1.4	20% / 3.8	21% / 1.68	25% / 3.5	20% / 3.6	35% / 3.85	35% / 3.85	40% / 6.0	27.68

Weighted Decision Matrix for "Shelter User" evaluating each concept against the customer requirements taking into account relative weight of requirements

Accessing Fluid (Water)						
Criteria \ Concept	Datum	Hand Pump	Pipe from Mountains	Collect Rainwater	Well Water	Use Alternative Liquid
Individual Households	0	+	-	0	0	0
Low Cost	0	0	-	0	0	+
No Electricity	0	0	0	0	0	0
Universal	0	0	0	-	0	+
Accomadate Both Genders	0	0	0	0	0	0
Low/Simple Maintenance	0	0	0	0	0	0
Local Materials	0	0	0	-	0	+
Environmental Conditions	0	0	0	-	0	0
Safety (for women)	0	0	0	0	0	0
Safety (health)	0	+	+	0	0	-
Σ +'s	0	**2**	1	0	0	**3**
Σ 0's	0	9	8	8	11	7
Σ -'s	0	0	2	3	0	1
Net Score	0	**2**	-1	-3	0	**2**

Pugh Matrix for "Access Water" evaluating each concept against the customer requirements

Accessing Fluid (Water)								
Design Criteria / Weighting Factor / Alternatives	Individual Households	Low Cost	Universal	Low/Simple Maintenance	Local Materials	Environmental Conditions	Safety (health)	Sum
	0.05	0.20	0.05	0.25	0.15	0.05	0.15	0.90
Datum	50% / 2.5	80% / 16	50% / 2.5	50% / 12.5	75% / 11.25	75% / 3.75	60% / 15	63.5
Hand Pump	75% / 3.75	80% / 16	50% / 2.5	60% / 15	75% / 11.25	75% / 3.75	80% / 12	64.25
Pipe from Mountains	25% / 1.25	50% / 10	35% / 1.75	40% / 22.5	60% / 9	75% / 3.75	80% / 12	60.25
Collect Rainwater	50% / 2.5	50% / 10	25% / 1.25	40% / 10	75% / 11.25	50% / 2.5	80% / 12	49.5
Well Water	50% / 2.5	80% / 16	70% / 3.5	60% / 15	75% / 11.25	75% / 3.75	60% / 9	61
Use Alternative Liquid	60% / 3	90% / 18	75% / 3.75	50% / 12.5	85% / 12.75	75% / 3.75	25% / 3.75	57.5

Weighted Decision Matrix for "Access Water" evaluating each concept against the customer requirements taking into account relative weight of requirements

Providing Visibility							
Criteria \ Concept	Datum	Water Bottle Light	Human-Powered Light	Lanterns	Reflective Strips	Solar-Powered Lights	Glowing Objects
Individual Households	0	0	0	0	0	0	0
Low Cost	0	0	-	0	0	-	0
No Water	0	0	0	0	0	0	0
No Electricity	0	0	-	0	0	-	0
Universal	0	0	0	0	0	0	0
Accomadate Both Genders	0	0	0	0	0	0	0
Low/Simple Maintenance	0	0	-	0	0	-	0
Local Materials	0	0	-	0	-	-	-
Environmental Conditions	0	0	+	+	0	+	+
Safety (for women)	0	0	+	+	0	+	+
Safety (health)	0	+	-	-	+	+	+
Sum +'s	0	1	2	2	1	3	3
Sum 0's	0	10	4	8	9	4	7
Sum -'s	0	0	5	1	1	4	1
Net Score	0	1	-3	1	0	-1	2
Continue?	n	y	n	y	-	n	y

Pugh Matrix for "Provide Visibility" evaluating each concept against the customer requirements

Provide Visibility								
Design Criteria / Weighting Factor / Alternatives	Individual Households	Low Cost	Universal	Low/Simple Maintenance	Environmental Conditions	Safety (Women)	Safety (health)	Sum
	0.05	0.24	0.10	0.19	0.14	0.14	0.14	1.00
Datum	20% / 1.0	35% / 8.4	30% / 3.0	35% / 6.65	5% / 0.7	5% / 0.7	5% / 0.7	21.15
Water Bottle Light	20% / 1.0	30% / 7.2	20% / 2.0	25% / 4.75	15% / 2.1	15% / 2.1	15% / 2.1	21.25
Human Powered Light	20% / 1.0	10% / 2.4	15% / 1.5	10% / 1.9	30% / 4.2	20% / 2.8	25% / 3.5	17.3
Solar Powered Light	20% / 1.0	5% / 1.2	15% / 1.5	10% / 1.9	30% / 4.2	30% / 4.2	25% / 3.5	17.5
Reflective Strips	20% / 1.0	20% / 4.8	20% / 2.0	20% / 3.8	20% / 2.8	30% / 4.2	30% / 4.2	22.8

Pugh Matrix for "Provide Visibility" evaluating each concept against the customer requirements

Store Waste					
Criteria \ Concept	Datum	Septic Tank	Lagoon	Settling Tank	Plastic Container
Individual Households	0	0	0	0	+
Low Cost	0	-	-	-	+
No Water	0	+	+	+	+
No Electricity	0	0	0	0	0
Universal	0	0	0	0	+
Accomadate Both Genders	0	0	0	0	0
Low/Simple Maintenance	0	0	+	+	-
Local Materials	0	-	0	0	+
Environmental Conditions	0	+	+	+	+
Safety (for women)	0	0	0	0	0
Safety (health)	0	+	+	+	+
Σ +'s	0	3	**4**	**4**	**7**
Σ 0's	0	6	6	6	3
Σ -'s	0	2	1	1	1
Net Score	0	1	3	3	6

Pugh Matrix for "Store Waste" evaluating each concept against the customer requirements

Store Waste									
Design Criteria / Weighting Factor / Alternatives	Individual Households	Low Cost	No Water	Universal	Low/Simple Maintenance	Local Materials	Environmental Conditions	Safety (health)	Sum
	0.05	0.20	0.10	0.05	0.25	0.15	0.05	0.15	1.00
Datum	50% / 2.5	70% / 14	10% / 1	50% / 2.5	50% / 12.5	80% / 12	70% / 3.5	25% / 3.75	51.75
Septic Tank	50% / 2.5	25% / 5	90% / 9	50% / 2.5	50% / 12.5	70% / 10.5	90% / 4.5	80% / 12	58.5
Lagoon	50% / 2.5	25% / 5	90% / 9	50% / 2.5	90% / 22.5	80% / 12	90% / 4.5	80% / 12	70
Settling Tank	50% / 2.5	25% / 5	90% / 9	50% / 2.5	90% / 22.5	80% / 12	90% / 4.5	80% / 12	70
Plastic Container	100% / 5	90% / 18	90% / 9	70% / 3.5	0% / 0	85% / 12.75	90% / 4.5	50% / 7.5	60.25

Weighted Decision Matrix for "Store Waste" evaluating each concept against the customer requirements taking into account relative weight of requirements

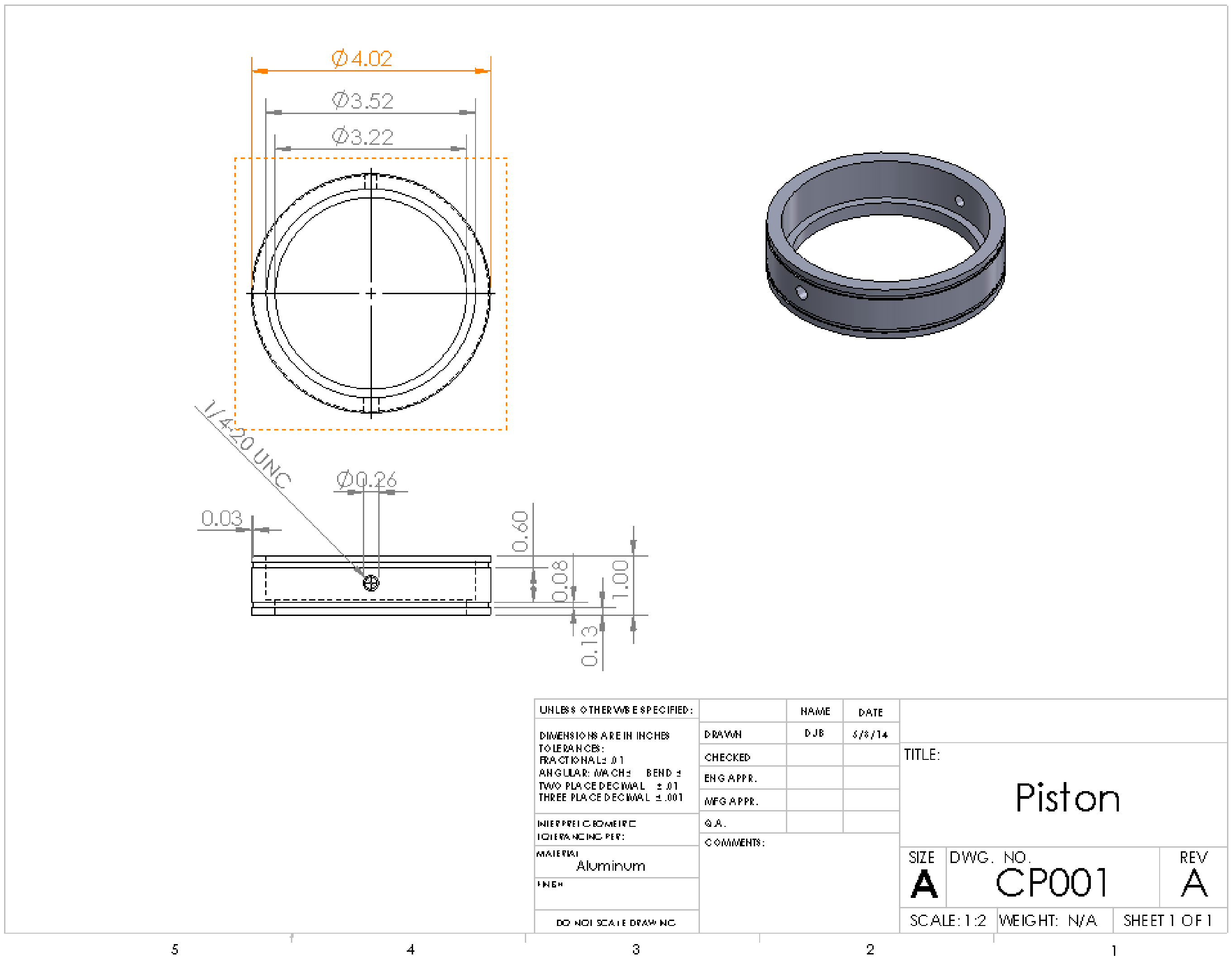
Transporting Waste							
Criteria \ Concept	Datum	Vacuum	Corkscrew Plumbing	Collection Bags	Pushing Stick	Bins on Wheels	Above-Ground Pipes
Individual Households	0	+	+	+	+	-	-
Low Cost	0	-	-	+	+	0	-
No Water	0	+	+	+	+	+	-
No Electricity	0	0	+	+	+	+	+
Universal	0	+	-	+	-	-	+
Accomadate Both Genders	0	0	0	0	-	0	0
Low/Simple Maintenance	0	-	-	+	+	0	-
Local Materials	0	-	-	-	+	-	+
Environmental Conditions	0	0	0	0	0	0	-
Safety (for women)	0	0	0	0	0	0	0
Safety (health)	0	+	0	-	-	-	+
Sum +'s	0	4	3	6	6	2	4
Sum 0's	0	4	4	3	2	5	2
Sum -'s	0	3	4	2	3	4	5
Net Score	0	1	-1	4	3	-2	-1
Continue?	n	y	n	y	y	n	n

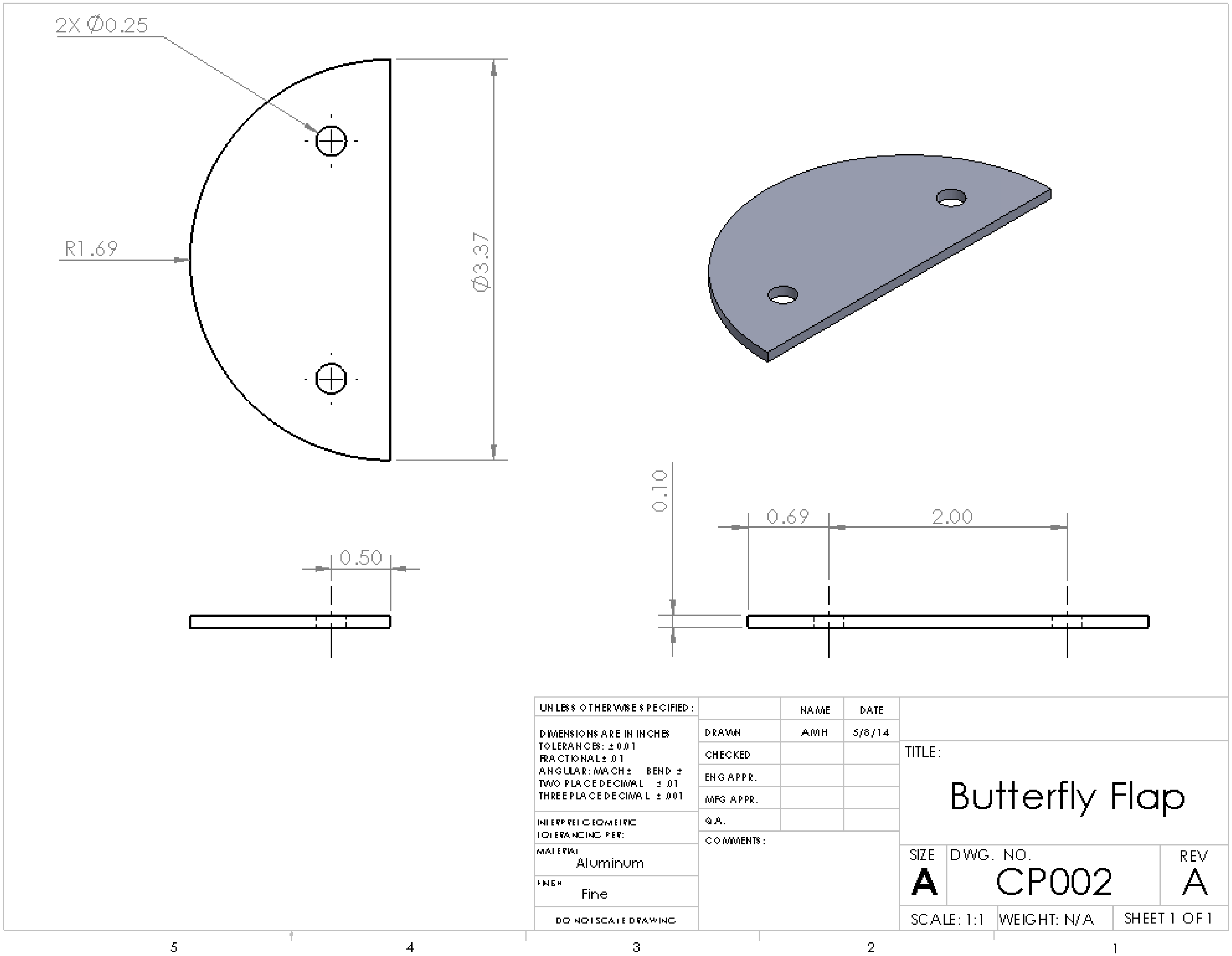
Pugh Matrix for "Transport Waste" evaluating each concept against the customer requirements

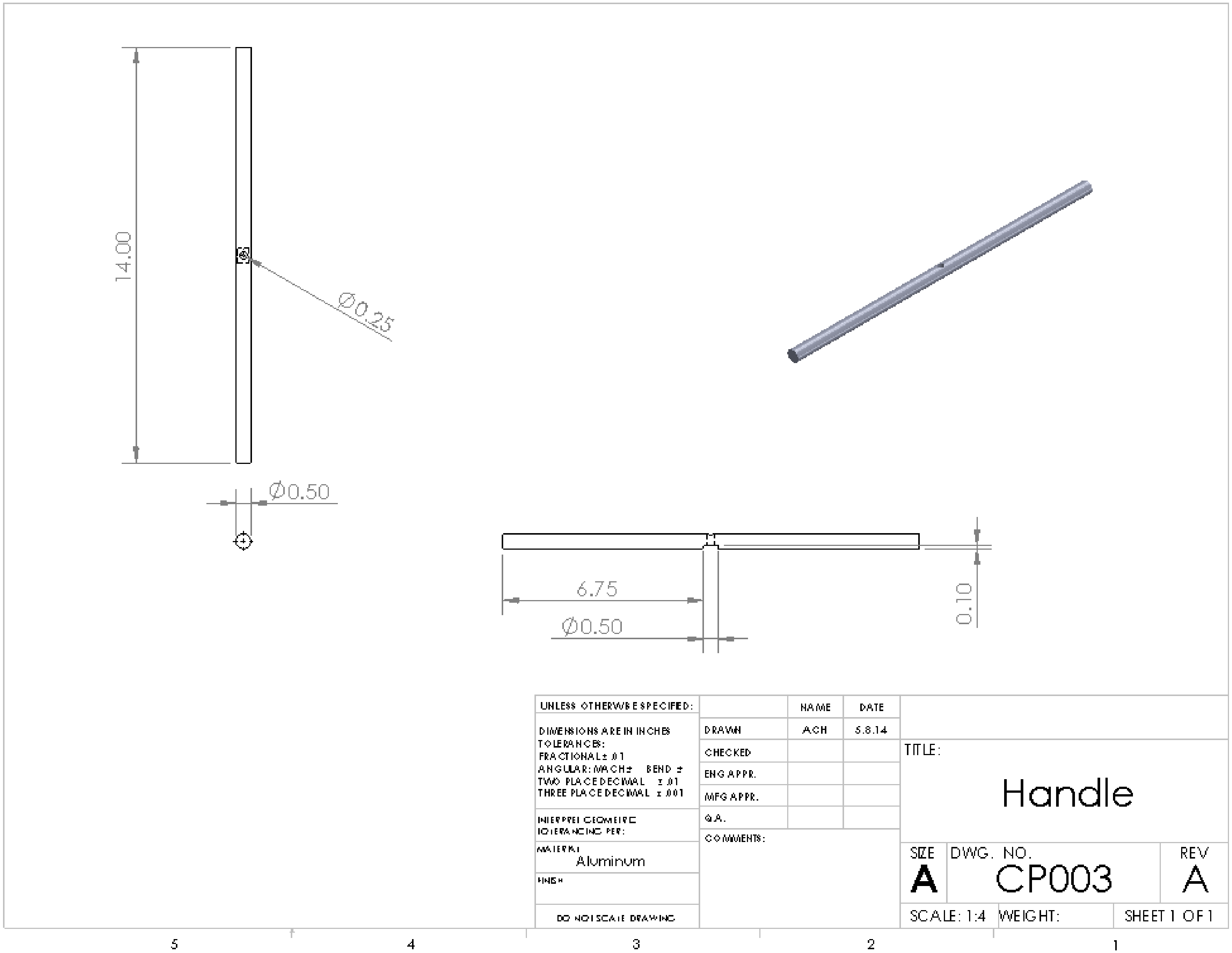
Transport Waste								
Design Criteria / Weighting Factor / Alternatives	Individual Households	Low Cost	Universal	Low/Simple Maintenance	Environmental Conditions	Safety (Health)	Safety (health)	Sum
	0.05	0.24	0.10	0.19	0.14	0.14	0.14	1.00
Datum	20% / 1.0	20% / 4.8	20% / 2.0	25% / 4.75	5% / 0.7	17% / 2.38	10% / 1.4	17.03
Vaccum/Pump	20% / 1.0	10% / 2.4	20% / 2.0	15% / 2.85	30% / 4.2	17% / 2.38	20% / 3.8	18.63
Corkscrew Plumbing	20% / 1.0	15% / 3.6	20% / 2.0	10% / 1.9	30% / 4.2	17% / 2.38	20% / 3.8	18.88
Collection Bags	10% / 0.5	20% / 4.8	15% / 1.5	20% / 3.8	10% / 1.4	17% / 2.3	15% / 2.1	16.4
Above Ground Plumbing	20% / 1.0	15% / 3.6	10% / 1.0	15% / 2.85	20% / 2.8	17% / 2.38	20% / 3.8	17.43
Bins on Wheels	10% / 0.5	20% / 4.8	15% / 1.5	15% / 2.85	5% / 0.7	17% / 2.38	15% / 2.1	14.83

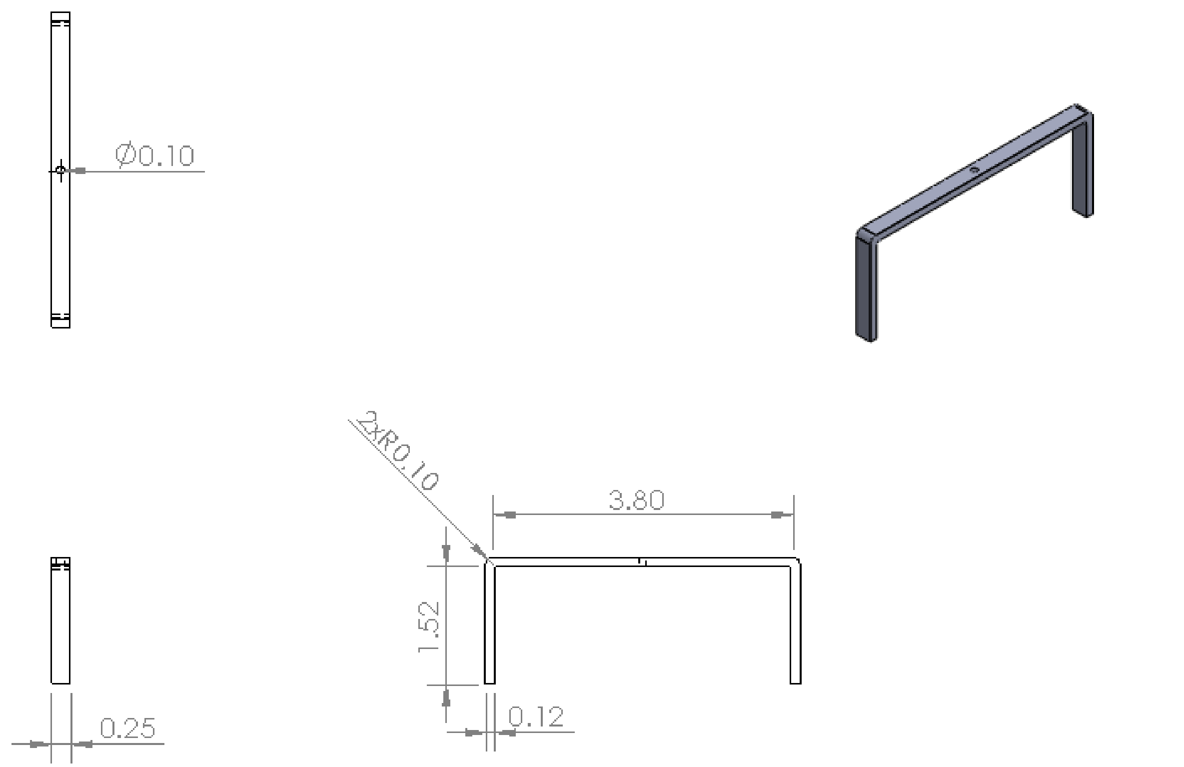
Weighted Decision Matrix for "Transport Waste" evaluating each concept against the customer requirements taking into account relative weight of requirements

Appendix C – Final Drawings and Part Lists



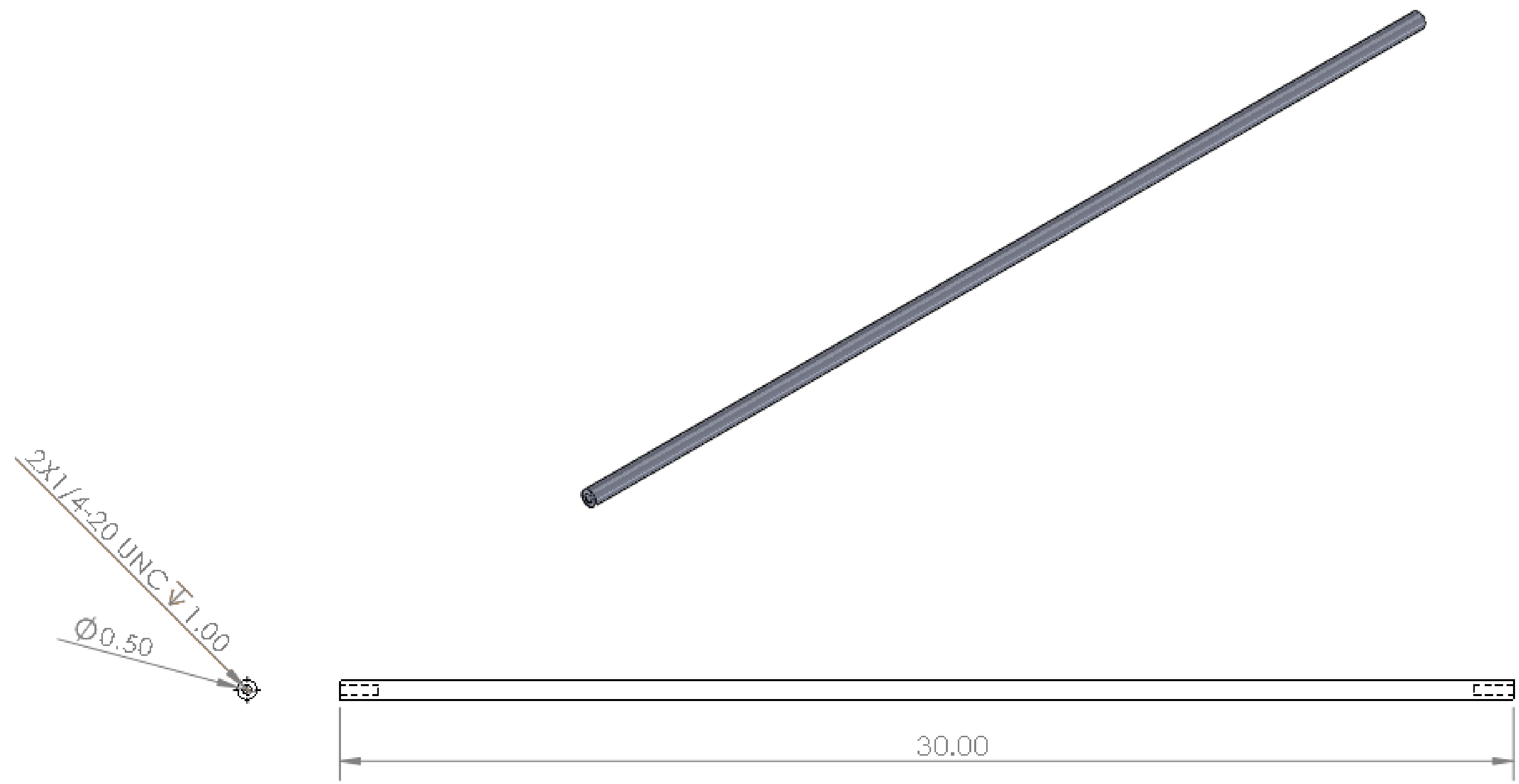

2X Ø0.25
R1.69
Ø3.37
0.50
0.10
0.69
2.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.01
FRACTIONAL± .01
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .001
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
Aluminum
FINISH
Fine
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
AMH
5/8/14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Butterfly Flap
SIZE
A
DWG. NO.
CP002
REV
A
SCALE: 1:1
WEIGHT: N/A
SHEET 1 OF 1
5
4
3
2
1


14.00
Ø0.25
Ø0.50
6.75
Ø0.50
0.10
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .01
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
ACH
5.8.14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Handle
SIZE
A
DWG. NO.
CP003
REV
A
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1



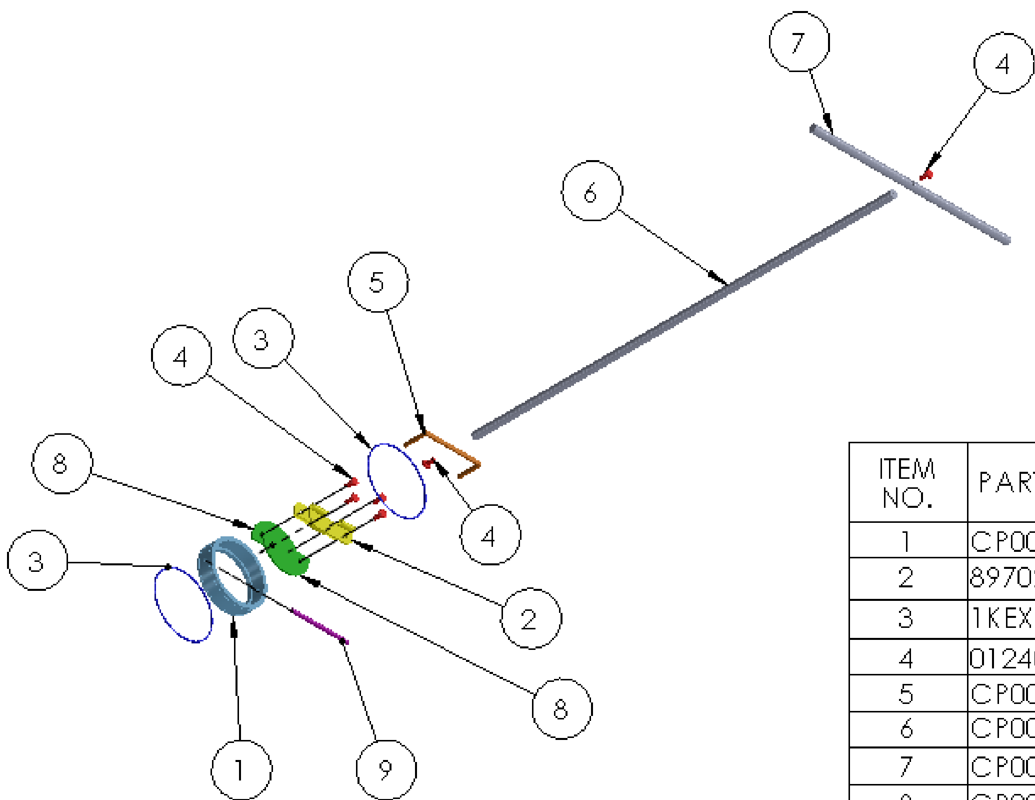
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .001	DRAWN	ACH	5.8.14	TITLE: Piston Bracket
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Aluminum Sheet	COMMENTS:			SIZE A — DWG. NO. CP005 — REV A
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:2 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .01 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .001	DRAWN	DJB	5/9/14	TITLE:
	CHECKED			Plunger Rod
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: Aluminum	COMMENTS:			SIZE A · DWG. NO. CP006 · REV A
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:8 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	CP001	Piston	1
2	897022	Flat Hinge	1
3	1KEX2	O-Ring 4in	2
4	01240	Hex Bolt 1/4-20x1"	6
5	CP005	Piston Bracket	1
6	CP006	Plunger Rod	1
7	CP003	Handle	1
8	CP002	Butterfly Flap	2
9	CP011	Hinge Rod	1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	DJB	5/8/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

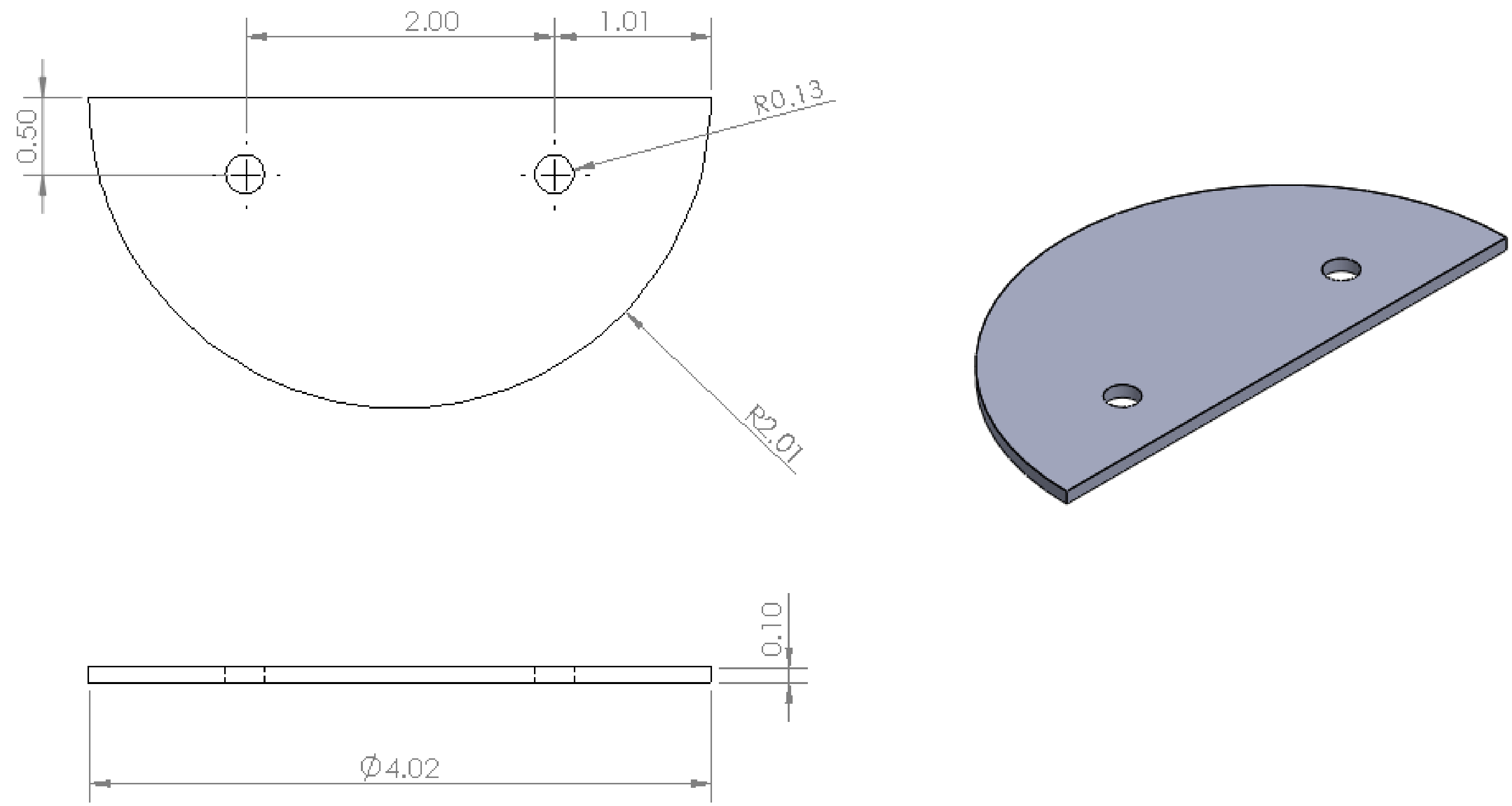
TITLE:

Piston Assembly

SIZE	DWG. NO.	REV
A	CP007	A

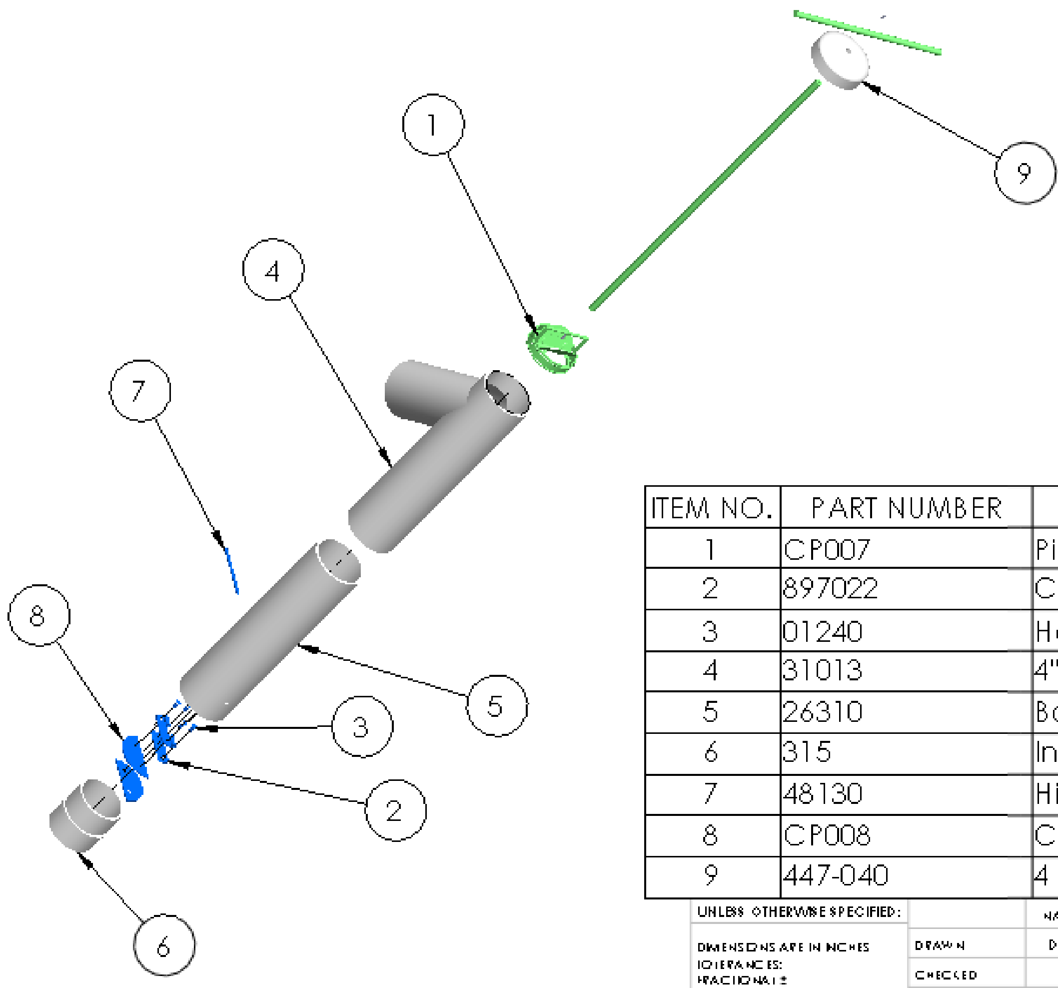
SCALE: 1:16 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .01 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .001	DRAWN	DJB	5/9/14	TITLE: Check Valve Flap
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Aluminum	COMMENTS:			SIZE A · DWG. NO. CP008 · REV A
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:1 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	CP007	Piston 2.0	1
2	897022	Check Valve Hinge	1
3	01240	Hex Bolt 1/4-20x1"	4
4	31013	4" White PVC Wye	1
5	26310	Bottom Pipe 4x18in	1
6	315	Internal Coupling 4in	1
7	48130	Hinge Rod Bottom	1
8	CP008	Check Valve Flap	2
9	447-040	4 in. Schedule 40 PVC Slip Cap	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	DJB	5/8/2014
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

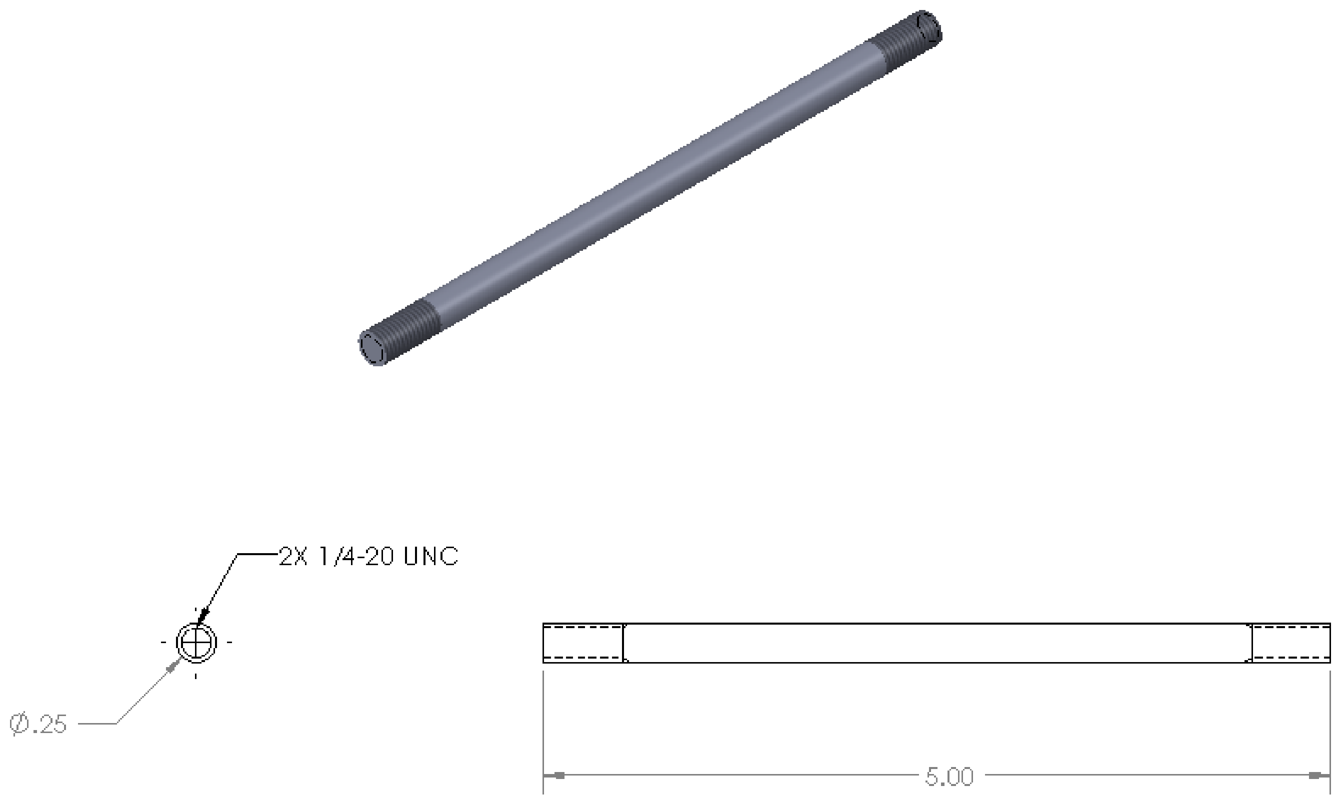
TITLE:

Pump Assembly

SIZE	DWG. NO.	REV
A	CP009	A

SCALE: 1:32 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	DJB	12/3/14
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Aluminum	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

TITLE:

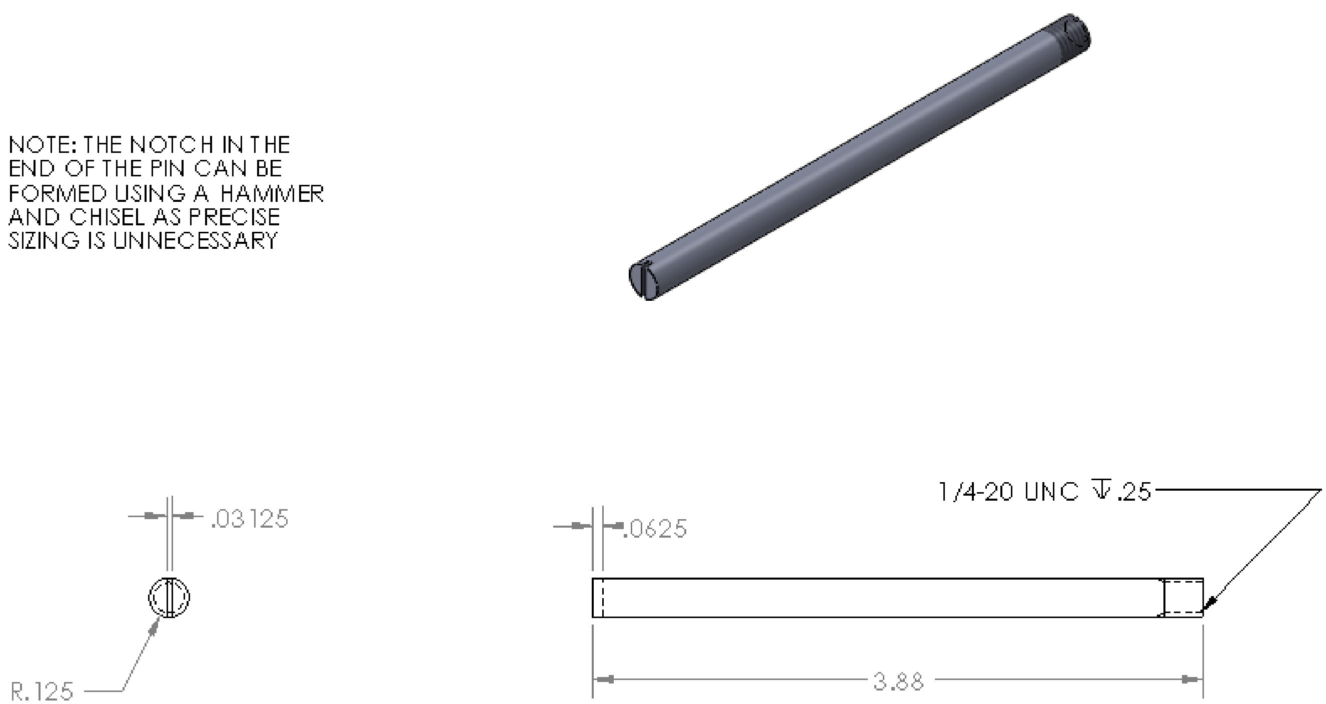
Check Valve Pin

SIZE	DWG. NO.	REV
A	CP010	A

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

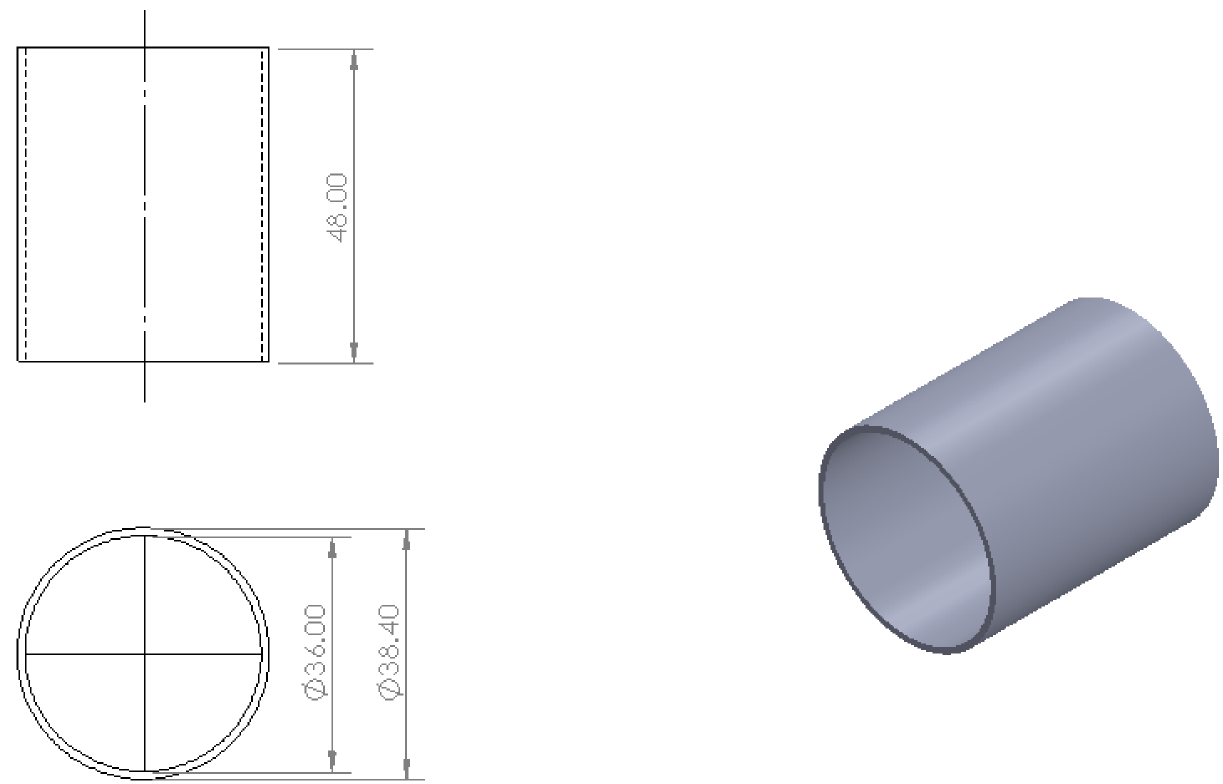
5 4 3 2 1

NOTE: THE NOTCH IN THE END OF THE PIN CAN BE FORMED USING A HAMMER AND CHISEL AS PRECISE SIZING IS UNNECESSARY



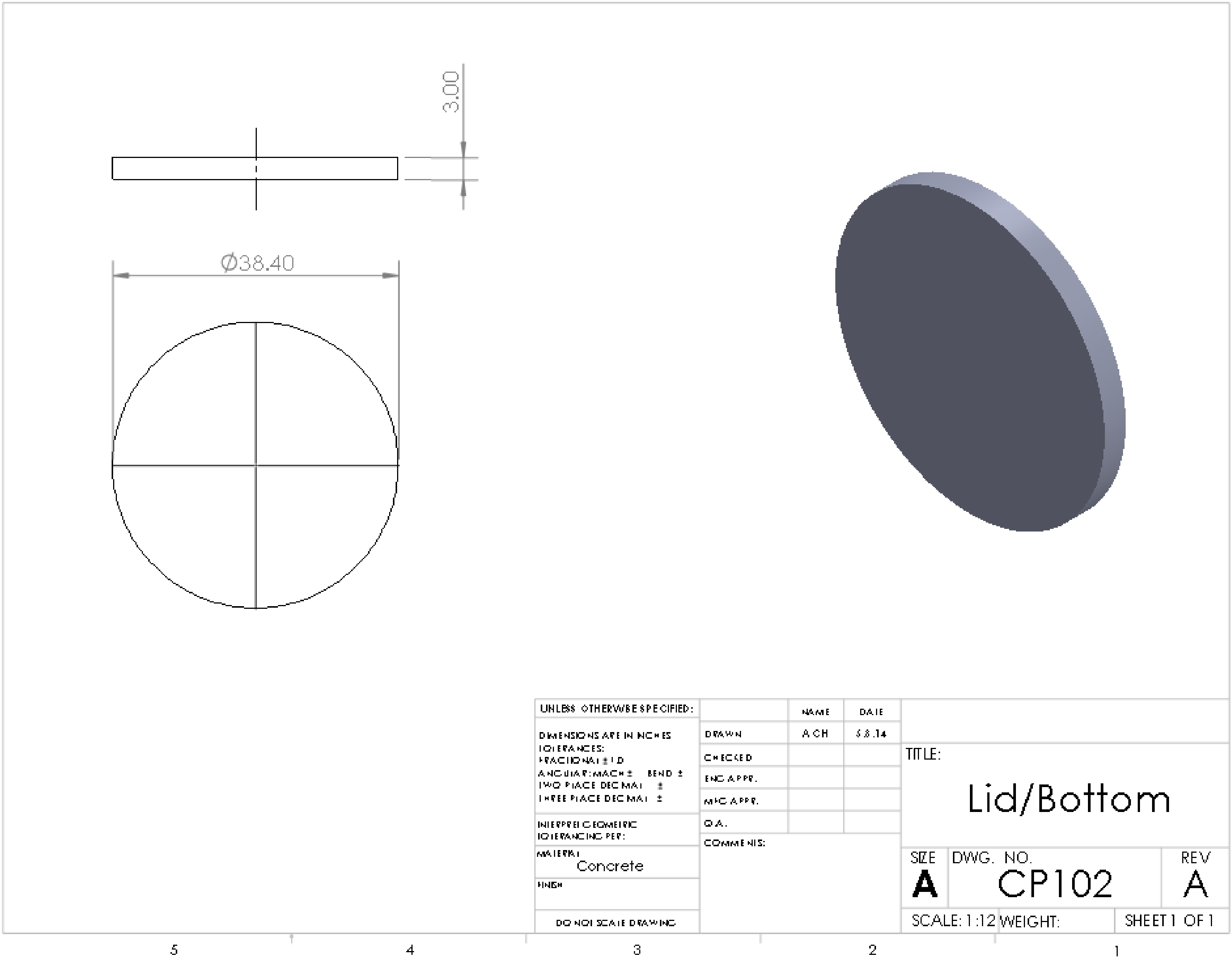
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	DJB	12/3/14	
	CHECKED			TITLE: Butterfly Valve Pin
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Aluminum	COMMENTS:			SIZE A — DWG. NO. CP011 — REV A
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:1 — WEIGHT: — SHEET 1 OF 1

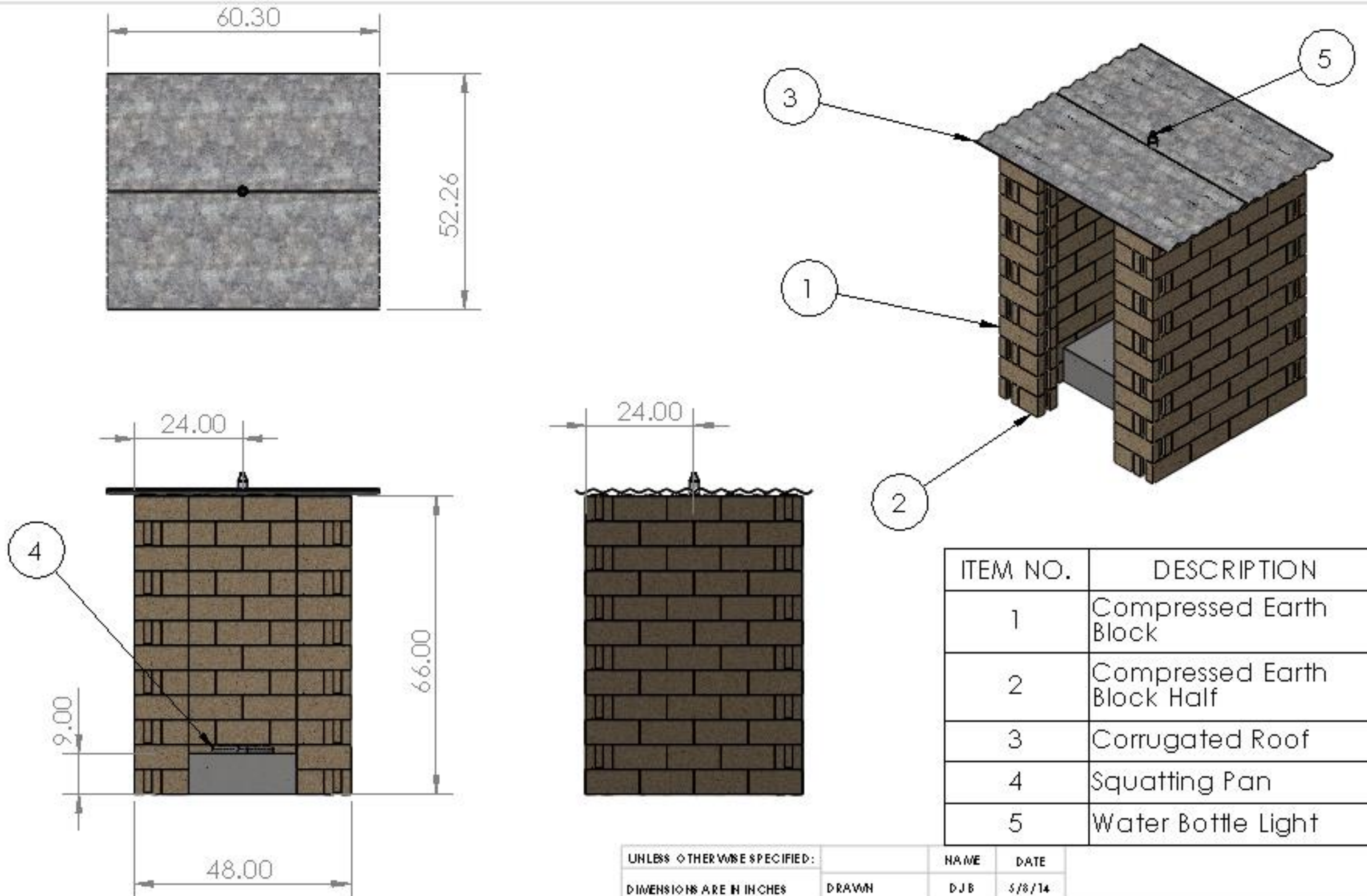
5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± 1.0 ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	ACH	5.8.14	TITLE: Waste Storage Pit
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Concrete	COMMENTS:			SIZE A · DWG. NO. CP101 · REV A
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:24 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1


3.00
Ø38.40
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Concrete
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
ACH
5.8.14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Lid/Bottom
SIZE
A
DWG. NO.
CP102
REV
A
SCALE: 1:12
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1



ITEM NO.	DESCRIPTION	QTY.
1	Compressed Earth Block	138
2	Compressed Earth Block Half	12
3	Corrugated Roof	1
4	Squatting Pan	1
5	Water Bottle Light	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	DJB	5/8/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

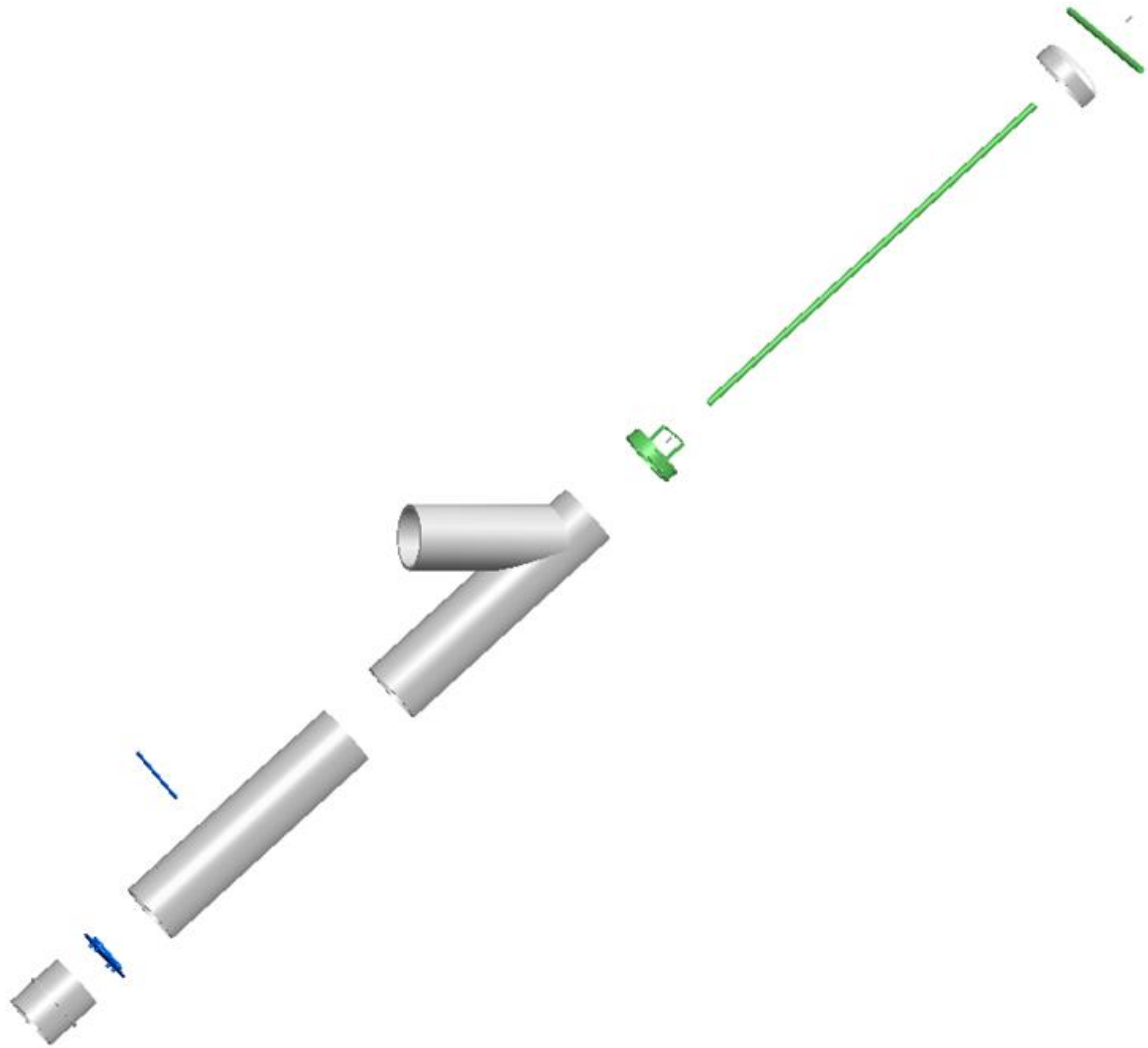
COMMENTS:

TITLE:

Shelter

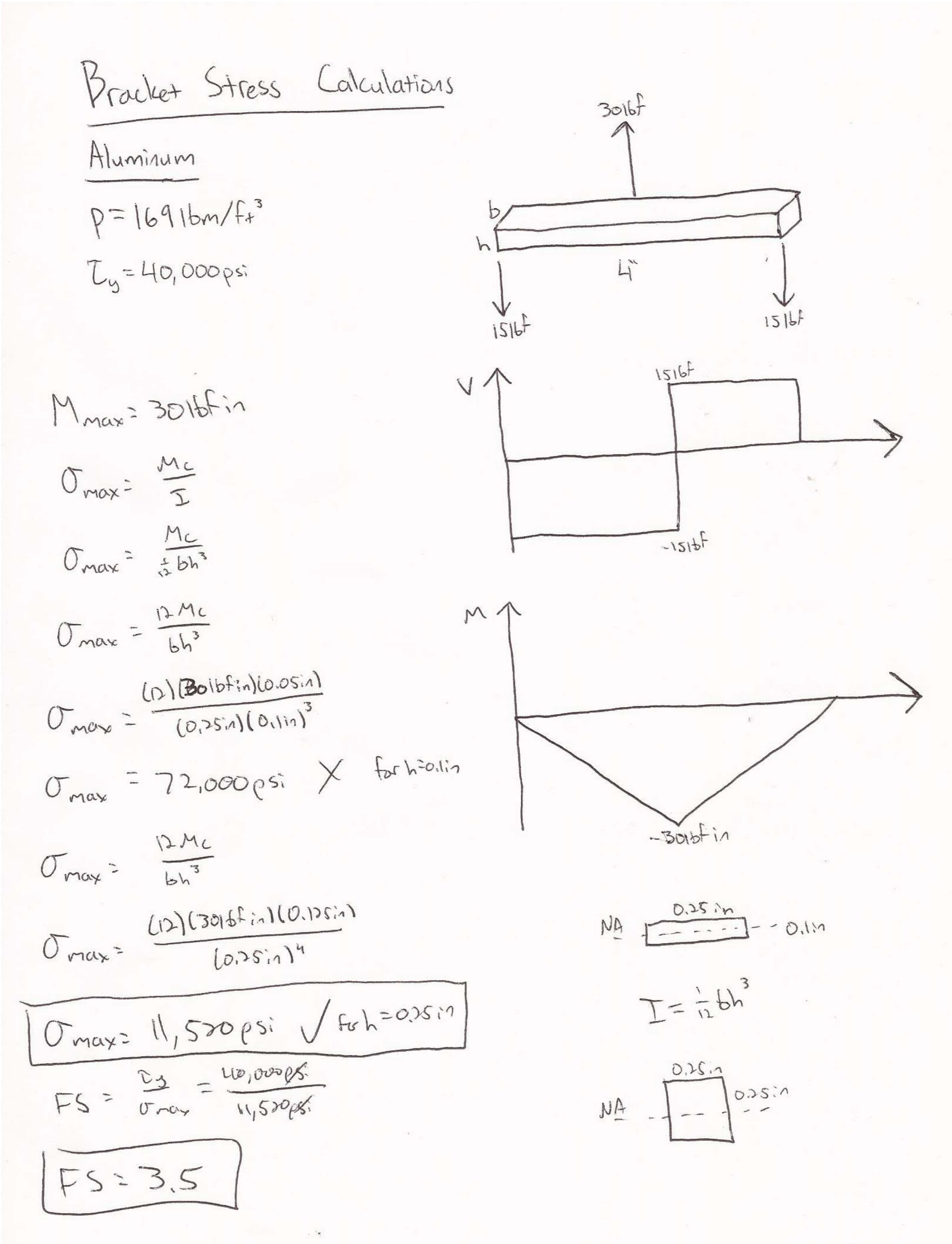
SIZE	DWG. NO.	REV
A	CP201	A

SCALE: 1:32 WEIGHT: SHEET 1 OF 1



Exploded view of the pump system showing both valves and the plunger with an abbreviated pipe segment

Appendix D – Supporting Analysis



Bracket Stress Calculations

Aluminum

$\rho = 169\ lbm/ft^3$

$\tau_y = 40{,}000\ psi$

$M_{max} = 30\ lbf\ in$

$\sigma_{max} = \frac{Mc}{I}$

$\sigma_{max} = \frac{Mc}{\frac{1}{12}bh^3}$

$\sigma_{max} = \frac{12Mc}{bh^3}$

$\sigma_{max} = \frac{(12)(30\ lbf\ in)(0.05\ in)}{(0.25\ in)(0.1\ in)^3}$

$\sigma_{max} = 72{,}000\ psi$ X for h = 0.1 in

$\sigma_{max} = \frac{12Mc}{bh^3}$

$\sigma_{max} = \frac{(12)(30\ lbf\ in)(0.125\ in)}{(0.25\ in)^4}$

$\sigma_{max} = 11{,}520\ psi$ ✓ for h = 0.25 in

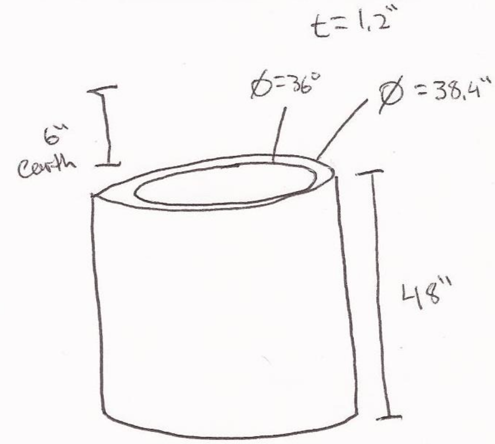
$FS = \frac{\tau_y}{\sigma_{max}} = \frac{40{,}000\ psi}{11{,}520\ psi}$

$FS = 3.5$

Stress calculations for plunger bracket

Pit Calculations

Concrete	Earth
$\rho = 150\,lbm/ft^3$	$\rho = 100\,lbm/ft^3$



$$\sigma = \frac{F}{A}$$

$$\rightarrow F = W_{earth} + W_{pit}$$

$$F = (m_{earth} + m_{pit})\,g$$

$$F = (\rho_{earth} V_{earth} + \rho_{pit} V_{pit})\,g$$

$$F = \left[\left(100\,\tfrac{lbm}{ft^3}\right)(4ft^3) + \left(150\,\tfrac{lbm}{ft^3}\right)(4ft^3)\right] 32.2\,ft/s^2$$

$$F = 1000\,lbf$$

$$\sigma = \frac{1000\,lbf}{140\,in^2}$$

$$\boxed{\sigma = 7.14\,psi}$$

$$\tau_y = 3000\,psi \leftarrow \text{conservative value}$$

$$FS = \frac{\tau_y}{\sigma} = \frac{3000\,psi}{7.14\,psi}$$

$$\boxed{FS = 420}$$

$$A = \pi\left(\frac{38.4}{2}\right)^2 - \pi\left(\frac{36}{2}\right)^2$$

$$A = 140\,in^2$$

$$V_{earth} = \pi\left(\frac{38.4\,in}{2}\right)^2 (6\,in)\left[\frac{ft}{12\,in}\right]^3$$

$$V_{earth} = 4\,ft^3$$

$$V_{pit} = \pi(37.2\,in)(1.2\,in)(48\,in)\left[\frac{ft}{12\,in}\right]^3$$

$$V_{pit} = 4\,ft^3$$

$$\sigma_\theta = \rho g h$$

$$\sigma_\theta = \left(0.072\,\tfrac{lbm}{ft^3}\right)\left(32.2\,\tfrac{ft}{s^2}\right)(4ft)$$

$$\sigma_\theta = 9.28\,psf$$

$$\boxed{\sigma_\theta = 1336\,psi}$$

$$FS = \frac{\tau_y}{\sigma_\theta} = \frac{3000\,psi}{1336\,psi}$$

$$\boxed{FS = 2.25}$$

Cylindrical concrete storage pit stress calculations

PIPE CALCULATIONS

DENSITY OF THE SLURRY

$$\rho_m = \frac{100}{\left[\frac{C_w}{\rho_s} + \frac{[100 - C_w]}{\rho_l}\right]}$$

C_w = weight of solid concentration [%]

ρ_s = density of the solid

ρ_l = density of the solid

$\rho_s \approx 1.0 \times 10^3 \, kg/m^3$

$\rho_l = 1.03 \times 10^3 \, kg/m^3$

$W_s = 4804.1 N$ ⟹ assuming Family household as about 8 people and that each person produces 0.75 lbs per day

$W_l = 14092.0 N$ ⟹ assuming 0.0023 lbs per day

$C_w = 25.4\%$

$$\rho_m = \frac{100}{\frac{25.4}{1.0 \frac{kg}{m^3}} + \frac{74.6}{1.03 \frac{kg}{m^3}}}$$

$$\rho_m = 1.14 \times 10^3 \frac{kg}{m^3}$$

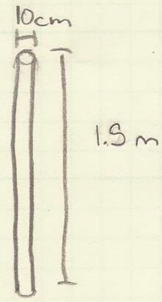
LIFTING FORCE

$$F = (\rho_m g h) A$$

$$F = \left(1.14 \times 10^3 \frac{kg}{m^3}\right)\left(9.81 \frac{m}{s^2}\right)(1. \; m)(0.008 \, m^2)$$

$$F = 110.8 N$$

$$F \approx 26 \, lb$$



Pump fluid calculations

SPECIFIC GRAVITY/DYNAMIC VISCOSITY OF SLURRY

$SG = 1.65$ ⇒ Found from online journal for slurry properties case study

$\mu = 70 \frac{N \cdot s}{m^2}$ ⇒ Assuming that the slurry is a shear-thinning fluid

VOLUMETRIC FLOWRATE

ASSUMPTIONS: - 4 strokes for the full length of the pipe
- Steady stroke rate of 1 stroke/s.

$\forall = h \cdot A$

$A = 0.008 \, m^2$

$h = 1.5 \, m$

$\forall = 0.01 \, m^3$

$\forall / stroke = \frac{0.01 \, m^3}{4 \, strokes}$

$\forall / stroke = 0.0025 \, \frac{m^3}{stroke}$

$\dot{\forall} = 0.0025 \, \frac{m^3}{s}$

VELOCITY

$V = \frac{\dot{\forall}}{A}$

$V = \frac{0.025 \, \frac{m^3}{s}}{0.008 \, m^2}$

$V = 0.30 \, \frac{m}{s}$

FRICTION FACTOR

$f = 90.96$ → Found from an online Chart

HEAD LOSSES AND PRESSURE DROPS

$H_L = 4.7 \, m$

$P_L = 76.1 \, kPa$

→ Using all of the values previously found with an input pump efficiency calculator online.

Pump fluid calculations continued

Appendix E – Gantt Chart

W	Task Name	Duration	Start	Finish	Predecessor
1	Sponsor Presentations	1 day	Tue 1/7/14	Tue 1/7/14	
2	Project Preference Form	1 day	Wed 1/8/14	Wed 1/8/14	
3	Intro Letter to Sponsor	2 days	Mon 1/13/14	Tue 1/14/14	2
4	Team Contract	3 days	Tue 1/14/14	Thu 1/16/14	
5	Background Research	7 days	Fri 1/17/14	Mon 1/27/14	
6	**Project Proposal**	**8 days**	**Sun 1/26/14**	**Tue 2/4/14**	
6.1	Problem Statement	1 day	Sun 1/26/14	Sun 1/26/14	
6.2	QFD House of Quality	3 days	Tue 1/28/14	Thu 1/30/14	7
6.3	Write Document	2 days	Fri 1/31/14	Mon 2/3/14	8
6.4	Send Project Proposal	0 days	Tue 2/4/14	Tue 2/4/14	9
7	**Ideation**	**11 days**	**Tue 2/4/14**	**Tue 2/18/14**	
7.1	Brainstorming	7 days	Tue 2/4/14	Wed 2/12/14	
7.2	Build Concept Models	3 days	Thu 2/13/14	Mon 2/17/14	12
7.3	Present Concept Models	1 day	Tue 2/18/14	Tue 2/18/14	13
8	**Preliminary Design Review**	**18 days**	**Tue 2/18/14**	**Thu 3/13/14**	
8.1	Pugh Matricies	2 days	Tue 2/18/14	Wed 2/19/14	
8.2	Decision Matricies	2 days	Thu 2/20/14	Fri 2/21/14	16
8.3	Gantt Chart	2 days	Tue 2/25/14	Wed 2/26/14	17
8.4	Write Document	3 days	Thu 2/27/14	Mon 3/3/14	
8.5	PDR Due	0 days	Tue 3/4/14	Tue 3/4/14	19
8.6	Present PDR to Sponsor	0 days	Thu 3/13/14	Thu 3/13/14	20
9	**Critical Design Review**	**44 days**	**Tue 3/11/14**	**Fri 5/9/14**	
9.1	Design FMEA & DVP	2 days	Tue 3/11/14	Wed 3/12/14	
9.2	Design Analysis Plan	2 days	Thu 3/13/14	Fri 3/14/14	
9.3	Spring Break	7 days	Sat 3/22/14	Sun 3/30/14	
9.4	DFMA	2 days	Tue 4/1/14	Wed 4/2/14	
9.5	Analysis and Test	10 days	Thu 4/3/14	Wed 4/16/14	
9.6	Design for Pump Sanitation	2 days	Sat 4/5/14	Mon 4/7/14	
9.7	Pump Analysis	3 days	Tue 4/8/14	Thu 4/10/14	
9.8	Pit Analysis	3 days	Tue 4/8/14	Thu 4/10/14	
9.9	Bracket Analysis	2 days	Mon 4/14/14	Tue 4/15/14	
9.10	BOM/CAD Modeling	8 days	Thu 4/17/14	Mon 4/28/14	
9.11	Write Document	8 days	Tue 4/22/14	Thu 5/1/14	
9.12	Create Presentation	5 days	Tue 4/22/14	Mon 4/28/14	
9.13	CDR Presentations	3 days	Tue 4/29/14	Thu 5/1/14	34
9.14	CDR Due	0 days	Fri 5/2/14	Fri 5/2/14	33
9.15	Present CDR to Sponsor	0 days	Thu 5/8/14	Thu 5/8/14	36
10	**End of Quarter Report**	**19 days**	**Tue 5/13/14**	**Fri 6/6/14**	
10.1	Order Parts	4 days	Tue 5/13/14	Fri 5/16/14	
10.2	Ethics Presentations	3 days	Tue 5/20/14	Thu 5/22/14	
10.3	Manufacturing and Test Review	1 day	Tue 6/3/14	Tue 6/3/14	
10.4	End of Quarter Report	0 days	Fri 6/6/14	Fri 6/6/14	
11	Summer Break	67 days	Sat 6/14/14	Sun 9/14/14	
12	India Trip?	7 days	Sun 9/7/14	Sun 9/14/14	
13	**Build/Test Protoype**	**40 days**	**Mon 9/15/14**	**Fri 11/7/14**	
13.1	Prototype Construction	25 days	Mon 9/15/14	Fri 10/17/14	
13.2	Prototype Testing	16 days	Sat 10/18/14	Fri 11/7/14	46
13.3	Accelerated Pump Pipe Corrosion Test	97 days	Tue 6/10/14	Wed 10/22/14	
13.4	Waste Composting Test	97 days	Tue 6/10/14	Wed 10/22/14	
13.5	Structure Material Failure Test	2 days	Sun 10/19/14	Mon 10/20/14	
13.6	Lighting Effectiveness Test	1 day	Mon 10/20/14	Mon 10/20/14	
13.7	Collection Pit Strength Test	6 days	Wed 10/22/14	Wed 10/29/14	
13.8	Bracket Strength	1 day	Wed 10/22/14	Wed 10/22/14	
13.9	Valve Leakage Test	1 day	Sun 10/26/14	Sun 10/26/14	
13.1	Roof Material Permeability	3 days	Sat 11/1/14	Tue 11/4/14	
14	**Senior Design Expo**	**10 days**	**Sat 11/8/14**	**Thu 11/20/14**	
14.1	Prepare for Expo	9 days	Sat 11/8/14	Wed 11/19/14	
14.2	Senior Design Expo	0 days	Thu 11/20/14	Thu 11/20/14	57
15	**Final Report**	**11 days**	**Fri 11/21/14**	**Fri 12/5/14**	
15.1	Prepare Final Report	10 days	Fri 11/21/14	Thu 12/4/14	
15.2	Final Report Due	0 days	Fri 12/5/14	Fri 12/5/14	60

The Work Breakdown Structure defines each task and subtask in the project plan

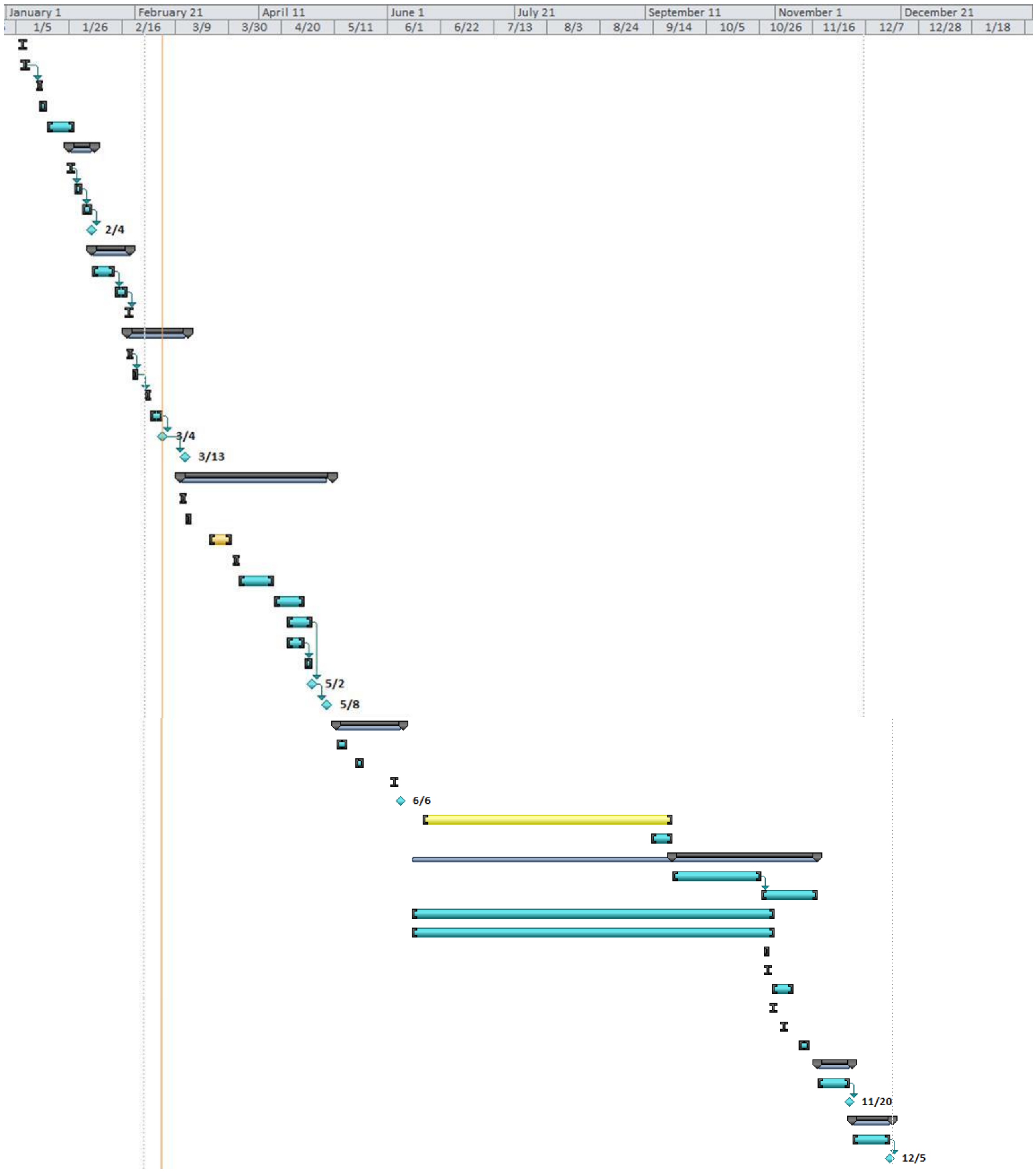


Figure 11b. Gantt Chart with timeline for each task and subtask including connections relating tasks to each other

Appendix F – Operation Manual

Assembly and Maintenance

Pit

Tools Required:
Metal Pit Die, Container and Shovel to mix Concrete, Pulley System, Flanges, Bolts, and Crescent Wrench

Notes:
Assembly of the sanitation system begins with the development of a pit. The goal of this design is to have a cement container with a large enough capacity to accommodate a maximum of two households' waste. The location of the pit should be close enough to the two households to minimize the piping needed to transport the waste from the location of the shelters to the concrete pit, but it should be far enough away from any other buildings so as to not cause any foundational failures.

Assembly/Disassembly:
(1) The development of the pit begins with the digging of the pit to the proper dimensions (38.40"ØX54" Depth).
(2) The cup-shaped pit die is then lowered, via a pulley, into the pit so that there is a gap in between the floor of the pit and the bottom of the mold.
(3) Then concrete is poured into the pit, forming a concrete pit lining.
(4) After the concrete is finished drying, the specialized lid is then formed on top of the lining. This lid will cover the top of the pit to protect from flooding and provide access for the waste to flow in and out of the pit. Two holes will exist for the intake pipe and the pumping pipe.
(5) The check valve-pipe assembly and the intake pipe is the lowered through the hole in the concrete lid, into the concrete pit.
(6) Finally, the top of the pipe (which should be exposed a foot above the concrete lid) is attached to the lid with a flange, and the rest of the hole is then filled with earth so that everything except the end of the pipe is covered. A cap will be placed on the end of the pipe for the six months prior to the collection of the waste to prevent flooding of the pit.
(7) Continued maintenance on the pit will prevent premature failure by leaking, fracturing, or erosion. Checking the sealing between the pipes and the lid will troubleshoot any additional leaking into the pit. Make sure that the area above the pit will not have too much foot traffic, or there is not any permanent forces are applied to the section of ground.

Check Valve/Vent Pipe

Tools Required:
Two Crescent Wrenches

Notes:
The process to assemble the check valve in the pit is crucial because this part of the pumping system is meant to be assembled permanently inside the pit. It would be difficult, but not impossible, to take the pipe above-ground to make any alterations or fix any issues that may arise. However, since this is undesirable, the construction of these parts is paramount because it is directly correlated to the amount of maintenance that will be required in the future.

Assembly/Disassembly:
(1) Place the coupling into the bottom portion of the long pipe and mark the height that the end of the coupling reaches into the pipe. This is the ledge that the check valve will rest on. Now measure 0.25 inches above this measurement and make two marks (both equidistant around the circumference of the pipe); this will be where the holes will be drilled for the check valve.
(2) Take the coupling out of the pipe and drill a 0.25 inch hole at both marks.
(3) Put the assembled flaps together so that the hinges are interlocking without the pin going through the center. While holding them with one hand, put them inside the pipe* and line up the through hole of the hinges with the two drilled holes.
*The put-together flaps should have enough clearance to fit in the inside of the pipe without interference, but if there is a problem with this then the flaps need to be filed down until they can freely move within the pipe and not be smaller than the inner diameter of the coupling.
(4) Put the threaded pin through the first hole and out of the second hole. Tighten the pin with nuts at both ends. Do not tighten the nuts too much because the pipe will deform and the check valve will not work.
(5) Flip the pipe upside down, so that the flaps will swing freely away from the bottom end of the pipe, and put the coupling back into the pipe. Now the flaps will lie flush on the lip created by the coupling when flipped right side up.
(6) Once the pit assembly is ready, place the pipe into the pit.
(7) Continued maintenance after installation will depend on the condition of the environment and the proper use of the pump. For the general checks, this will mostly be due to the corrosiveness of the waste interacting with the aluminum. From general research, this check may have to be done every few years to see if replacement is necessary. Conditional maintenance will be onsite at the first indication of weaker performance. This happens when the flaps do not properly close, and the fix is to simply take the pipe out of the pit and readjust the flaps by hand to make sure they close.

Shelter/Housing

Tools Required:
Two Crescent Wrenches

Notes:
The shelter is basic enough of a design for easy maintenance, but strong enough to withstand the environment so that safety will not be much of a concern and less maintenance will be required from the user. The bottle light works with moonlight; however, if the sky isn't clear then the shelter will not be lit up. Attachment of the corrugated roofing is important for the concentration of the light being refracted by the bottle; if there are cracks in the sealed joint, then the light may not have its full effect.

Assembly/Disassembly:
(1) Maintenance on the shelter depends on situational circumstances. The shelter is meant to be a permanent structure inside/very close to an individual household, so disassembly isn't intended.
a. Fixing the seal on the water bottle or the joint would entail removing the existing sealant with a solvent and reapplying a new layer of sealant.
b. If the water bottle leaks, or becomes dysfunctional, replacing it may be difficult due to the fact that it has chlorine in the water. So it would be helpful to have these bottles be easily accessible.
c. A repair of the earth blocks, which can be due to weather and external forces, may be difficult due to the vitally of each earth block with respect to the entire structure. This will take complete disassembly of the entire structure, replacing the one block, and reconstructing the structure.

Modular Pump Head

Tools Required:
Flathead Screwdriver, Two Crescent Wrenches

Notes:
The pump head should always be handled with care as its purpose is to service multiple pits. All assembly and disassembly should be done with sanitary gloves. In addition to the tools, spare components should be kept including lock washers, bolts, and nuts.

Assembly/Disassembly:
(1)The band clamp has two screws that ratchet their respective metal bands. Use a flathead screwdriver to turn the screws counterclockwise and loosen the band clamp. Remove the pump head.
(2)Hold the piston handle steady and use a crescent wrench to remove the bolt holding the piston to the piston rod. Hold the piston rod steady and use a crescent wrench to remove the bolt holding the piston handle to the piston rod. Remove the piston, rod, and handle from the pipe fittings.
(3)Remove pipe fittings by maintaining a strong grip on one while pulling and twisting on another. Repeat so that you have three pipe fittings: short piece of pipe, wye, and pump cap.

(4)Take the piston assembly and use a flathead screwdriver to remove the hinge pin.
(5)Take one of the valve flaps and hold the nut with one crescent wrench and spin the bolt head counterclockwise with the other wrench. You can hold the bolt head steady and loosen the nut if preferred. Repeat until all four bolts are removed from both flaps.
(6)Clean all components with bleach and a brush. Rinse with water.
(7)Replace lock washers, bolts, nuts, or other parts as needed.

Pumping Setup and Procedure

Required tools:
Flathead screwdriver

Operation:
(1)Remove pipe cap. Position piston into pipe. Seal pump head assembly to pipe with band clamp using a flathead screwdriver. Ensure wye exhaust is pointed towards filling area.
(2)Start with a fast and steady upstroke.
(3)Immediately follow up with a medium and steady down stroke.
(4)Repeat steps 2-3 with a constant rhythm.
(5)Waste will begin to flow, continue constant rhythm until the pit is emptied.

Notes:
If pumping is interrupted and the fluid level is below the piston valve upon starting to pump again, the pump will require a few good strokes to prime. If this is the case, repeat steps 2-3 at higher speeds if necessary. Once the pump is primed and waste begins to flow, return to previous speeds and constant rhythm.